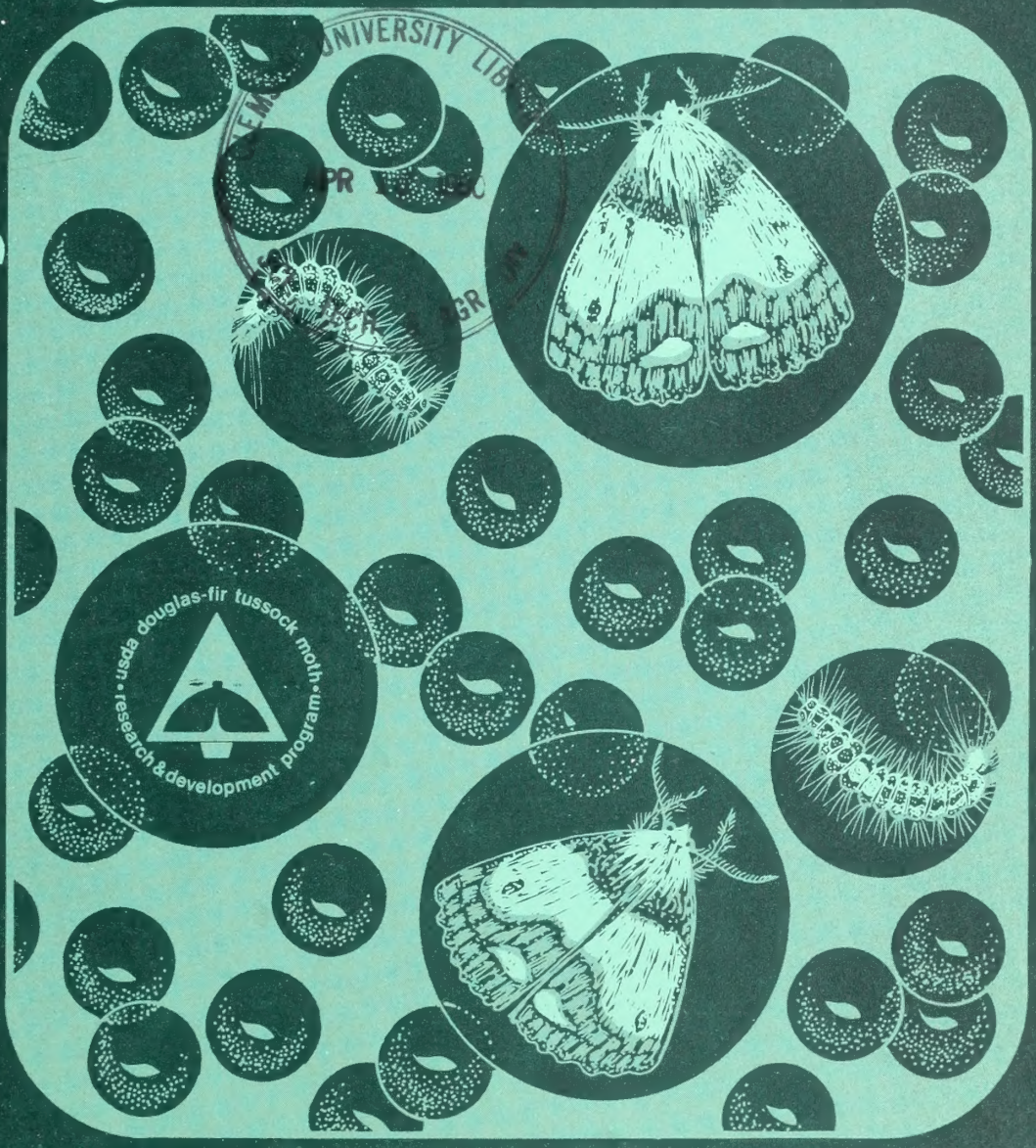
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Documentation of the Douglas-Fir Tussock Moth Outbreak-Population Model



By J. J. Colbert, W. Scott Overton, and Curtis White

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Reference Abstract

Documentation of three model versions: the Douglas-fir tussock moth population-branch model on (1) daily temporal resolution, (2) instar temporal resolution, and (3) the Douglas-fir tussock moth stand-outbreak model; the hierarchical framework and the conceptual paradigm used are described. The coupling of the model with a normal-stand model is discussed. The modeling convention and algorithm used are also discussed.

KEYWORDS: Population dynamics, defoliation damage, outbreak prediction, models, Douglas-fir tussock moth, *Orgyia pseudotsugata*.

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INTRODUCTION

This paper documents the mathematical form and computational framework of the Douglas-fir tussock moth (DFTM) stand-outbreak model. The model is constructed to simulate outbreaks of Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough)), a defoliator of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), and the true firs (*Abies* spp.) in western North America. The details of the model's background, its historical development, and the basis for formulation of its present structure and functional forms will be covered in another paper, as will documentation of model behavior.

The conceptual structure of the DFTM model provides a perspective on the relation of the various models developed. Three versions of the DFTM outbreak-population model were developed. Version 1.2, presented here, is at daily resolution and differs little from the original version (V1.1) conceived in 1974. The second version presented (V2.2) was originally developed (V2.1) to reduce computing costs and necessitated only minor alterations. These two versions follow the insect on a model branch through 1 year. This branch model became the operational unit of the stand-outbreak model (V3.1). Details of the coupling relation between the normal-stand model and the DFTM stand-outbreak model follow the overview of the general model structure.

A summary of the FLEX processing algorithm and notational convention precedes detailed documentation of the models. Adjustments to the current algorithm were necessitated by the DFTM stand-outbreak model structure, and these are detailed next. The computational framework in which the models are embedded is discussed in these two sections.

A short discussion, preceding the details of each model version, gives the relations among the three model versions and how they derive from each other. The detailed FLEXFORMS, summarizing model structure and parameterization, follow.[1/] Next are the specifics of file manipulation used in the third model version. This includes a more detailed discussion of the computational order discussed in general in another section.

Last is a description of the stand-postoutbreak model. This is the filtering mechanism that assigns mortality and growth impacts to the stand of trees. These result from defoliation of the model branch as transformed by the whole-tree-defoliation equation.

[1/] A FLEXFORM is a form developed for presenting the details of a component module of a model described in the FLEX paradigm.

THE GENERAL MODEL STRUCTURE

A hierarchical structure is conceptualized for the general model: each level is a dynamic unit of the level above (figures 1 and 2).

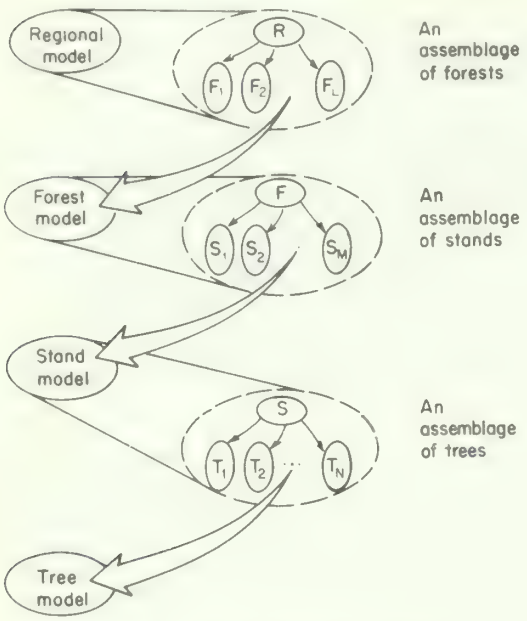


Figure 1.--How various models assemble into the hierarchical model. A region (R) consists of a number (L) of forests (F), a forest consists of a number (M) of stands (S), and each stand consists of a number (N) of trees (T).

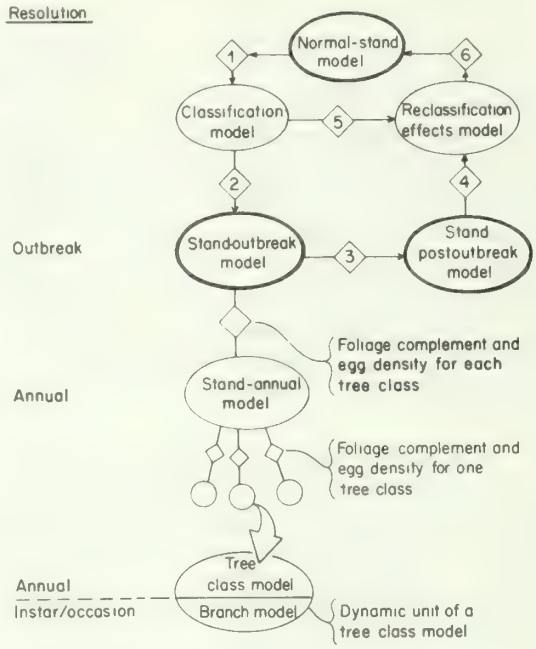


Figure 2.--Hierarchical organization of the DFTM stand-outbreak model relative to the normal-stand model.

A. Regional model: The socioeconomic context of the forest.
Resolution: 1 century; not implemented.

B. Forest model: An explicit assemblage of ecotype-stand units.
Resolution: 1 rotation; not implemented.

C. Stand model:
(a) Normal-stand model: An assemblage of trees of varying size and species, in a specific ecological and management regime.
Resolution: 1 decade; not implemented.
(b) Stand-outbreak model: An assemblage of tree classes prescribed by the effective resolution of knowledge of stand conditions and insect population levels. The conceptual structure of an outbreak is patterned after the observed sequence of population "phases" of Wickman et al. (1973). The successive years of an outbreak are parameterized according to phase-specific mortality vectors and other population properties.
Resolution: Duration of outbreak, 4 years.

(c) Stand-postoutbreak model: Translates the effects of defoliation into mortality, top-kill, and reduction of growth for each tree class and covers delayed mortality and remedial management practices.
Resolution: Duration of postoutbreak period, 6 years.
(d) Stand-annual model: The potential of integration over tree classes at the end of each year effectively imposes a stand-annual structure on the assemblage of tree classes. Redistribution of eggs over the tree classes in the stand is determined in this model.
Resolution: 1 year.

D. Tree model:
(a) Normal-tree model: The rules of normal growth and survival of a tree, of specific species, size, and age and of specific ecological and stand regimes.
Resolution: 1 year; not implemented.
(b) Tree-class model: A class of trees is represented by a typical tree. Defoliation of the typical tree over a season is derived from the branch model.
Resolution: 1 year.
(c) Tree-outbreak model: Normal growth increments and survival are modified by the degree of defoliation as determined from the branch model. The tree-outbreak model is simply a branch model, coupled or linked over seasons, with outputs translated at the end of the outbreak into the effects of defoliation on tree mortality, top-kill, and growth. This model does not explicitly appear, being subsumed by the stand-outbreak model. Effects of defoliation are relegated to the stand-postoutbreak model.
Resolution: Duration of outbreak and postoutbreak periods.[2/]

E. Branch model: Contains the rules of growth and survival of tussock moth, branch defoliation, and the production of new foliage and loss of old foliage by the branch; specific for ratio of eggs to foliage, for nominal ratio of new to old foliage, and for species of tree and year (phase) of outbreak. Standardization of the total biomass of foliage on the model branch (100 grams for Douglas-fir and 144 grams for grand fir (*Abies grandis* (Dougl.) Lindl.) allows specification of only two variables, percent new foliage and eggs (per total grams of foliage).

The mechanisms of the branch model are conceptualized at a daily resolution, with runs spanning one season. Initial conditions for a season run are identifiable from the terminating condition of a season run which provides the capacity to couple several seasons (years) together. In the daily resolution branch model, days are occasions.

[2/] The postoutbreak period has been set at 6 years so that the outbreak and postoutbreak periods will sum to the resolution of the normal-stand model.

For efficiency in computing, the daily resolution model was collapsed into an instar resolution model. This changes little and reduces the number of occasions in a season.

We can now identify several levels of temporal resolution: outbreak (containing several phase-specific years), year (containing several occasions), and occasion.

IDENTIFICATION OF COUPLING VARIABLES

In this outline of the couplings between the different models, Arabic numerals correspond to those in the numbered diamonds in figure 2.

1. Outputs of the normal-stand model and inputs to the classification model: Those state variables and parameters of the normal-stand model needed to assign trees of the stand to the classes of the stand-outbreak model.

2. Outputs of the classification model and inputs to the stand-outbreak model:
   - i. The number of tree classes in the stand;
   - ii. For each tree class, represented by a "typical tree":
     - a. The number of trees in the class;
     - b. The foliage composition of the model branch: Biomass of foliage and percent new foliage;
     - c. Egg density;
     - d. Species;
     - e. The weighting factor to account for relative contribution of a tree in the class to stand foliage biomass and insect population density;
   - iii. Ecological or site-specific model parameters.

3. Outputs of the stand-outbreak model and inputs to the stand-postoutbreak model for each class of trees in the stand:
   - i. Defoliation of the model branch after each season during the outbreak;
   - ii. Tree defoliation at the end of the outbreak.

4. Outputs of the stand-postoutbreak model and inputs to the reclassification-effects model, for each tree class:
   - i. Direct mortality; proportion of trees that die as a direct result of defoliation;
   - ii. Secondary mortality; proportion of trees that suffer secondary mortality in the postoutbreak period, identified as:
     - a. Bark beetle mortality;
     - b. Other mortality caused by the outbreak;
     - c. Noncausal mortality;
   - iii. Top-kill; proportion of trees in each top-kill subclass. Each subclass is defined in terms of height reduction. An additional output, the proportion of the nominal diameter-growth increment actually achieved is also given;

iv. No top-kill; proportion of trees that suffer neither top-kill nor mortality; and for these trees, the damage expressed as:
   a. Proportion of the nominal height-growth increment actually achieved;
   b. Proportion of the nominal diameter-growth increment actually achieved;

v. Factors for delayed reduction of growth beyond the postoutbreak period.

5. Outputs of the classification model and inputs to the reclassification-effects model: The record of which trees were assigned to the various classes.

6. Outputs of the reclassification-effects model and inputs to the normal-stand model: The allocation of mortality factors to the trees of the stand and the updating of growth increments to cover the outbreak period.

ABSTRACT OF THE FLEX CONVENTION AND ALGORITHM

The conceptual basis of FLEX is the identification of several kinds of variables and functions in the context of a general algorithm for dynamic behavior. Identify:

$\underset{\sim}{x}$, the vector of state variables;

$\underset{\sim}{y}$, the vector of output variables (functions of state variables);

$\underset{\sim}{z}$, the vector of input variables;

$\underset{\sim}{b}$, $\underset{\sim}{r}$, two vectors of constants (model parameters).

The update algorithm is a simple difference equation

$$\underset{\sim}{x}(k+1) = \underset{\sim}{x}(k) + \underset{\sim}{\Delta}(k)$$

with $\Delta(k)$ constructed as a sum of internal variables that are identified as f function values. These functions account for fluxes (flows) between state variables. Flux from x_i to x_j is f_{ij};

$$f_{ij} = f_{ij}(k,\underset{\sim}{z},\underset{\sim}{x},\underset{\sim}{g},\underset{\sim}{s},\underset{\sim}{b},\underset{\sim}{r});$$

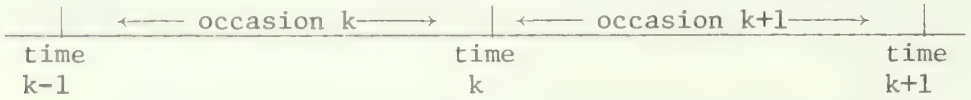
where g and s are vectors of functions; f_{ii} is a source or sink for x_i depending on the sign of f_{ii}. The g functions are intermediate functions--internal variables that are used extensively,

$$g_i = g_i(k,z,x,b,r).$$

The s functions, or special functions, are included for further modeling and programing flexibility; these are implemented as FORTRAN[3/] subroutines and are therefore much more general. Details of how this process is implemented are given in the FLEX users' manual (White and Overton 1977).

[3/] FORmula TRANslating system--a language used to express computer programs by arithmetic or logical formula.

The model processor outputs the initial conditions read at time 0, and from this point forward uses the values of the variables at time k to compute the values of the state variables at time k+1. The processor uses the values for time k to compute the outputs for time k+1. This accounts for actions taking place during occasion k+1.



In a terminal (or FLEX) module the algorithm may be summarized as follows:

(1) Receive (or calculate) inputs and store the values of $\underset{\sim}{z}$ using the z functions.
(2) Calculate and store the values of the g functions.
(3) Calculate and store the values of the f functions.
(4) Construct the update vector, $\underset{\sim}{\Delta}$.
(5) Update the state variables.
(6) Calculate and store (generate outputs) and values of $\underset{\sim}{y}$ using the y functions.

A time step k may be subdivided into q subintervals indexed by k' = 0, 1, ..., q - 1. Then define:

$$\underset{\sim}{x}(k) = \underset{\sim}{x}(k, 0),$$
$$\underset{\sim}{x}(k, k' + 1) = \underset{\sim}{x}(k, k') + \underset{\sim}{\Delta}(k, k'),$$
$$\underset{\sim}{x}(k + 1) = \underset{\sim}{x}(k, q);$$

k' is added to the g and f function arguments. This capability implies an additional step, 5a, in the above sequence:

(5a) Increment k' and compare to q where q is the resolution ratio. If less than q, return to step 2, otherwise proceed to step 6.

Processing of a ghost (REFLEX) module, one that has control over submodules, requires a modified procedure; steps 3, 4, and 5 are replaced by step 3a:

(3a) Call and process subsystems (submodules), which in turn update the values of the state variables in ghost. Then continue with step 5a.

The current FLEX algorithm assumes that a division of one time-step into q subintervals within a terminal (FLEX) module is being done to implement a solution to a set of differential equations, and accordingly only 1/q of the update (Δ) value is added to each variable. In module S_1 of version 3, this capacity is used differently; an event structure is **assumed** and a full update on each variable is desired. Because q = 10 (representing the 10 occasions in a season), each f function is multiplied by 10 to nullify the automatic multiplication by 1/q (White and Overton 1977, p. 21 and 32).

The symbol, x*, represents **implicit** state variables, carried for computational convenience internal to the FORTRAN code of a function (e.g., a g function). These are available to no other functions and will not appear in the list of explicit state variables.

VECTOR PROCESSING IN FLEX2

The current version of the DFTM stand-outbreak model makes use of some of the conceptual structure of the FLEX paradigm that is not explicitly a part of the current algorithm used by the model processor as detailed in the FLEX users manual. The following explanation will clarify a newly adopted notational convention, its conceptual meaning in the paradigm, its place in the algorithm, and its implementation using the current version of the processor.

In the FLEX paradigm, $\underset{\sim}{x}$, the vector of state variables, may contain elements that are themselves vectors--usually when a class II system is being considered, a system in which each subsystem has the same structure and function, as in a population of individuals that have the same rules of behavior. Thus, $\underset{\sim}{x}_i$ may be an element of $\underset{\sim}{x}$. For example, $\underset{\sim}{x}_i$ might represent the biomasses of each of the individuals in a population, with an element of $\underset{\sim}{x}_i$ the biomass of a particular individual. The notational convention is established that $\underset{\sim}{x}$ is the vector of state variables; $\underset{\sim}{x}_i$ is a vector element of $\underset{\sim}{x}$; and x_{ij} is a scalar element of $\underset{\sim}{x}_i$.

Only the homogeneous case is allowed, so that each member subsystem of the class II system has the same state variable structure. A g function that operates on $\underset{\sim}{x}_i$ is a vector valued function. $\underset{\sim}{g}$ is the vector of intermediate functions with g_i an element of this vector. $\hat{g}_i$ is a scalar value of g_i where the caret notation is used to signify an actual value of the function. When g_i operates on the vector $\underset{\sim}{x}$, it may produce a vector $\underset{\sim}{\hat{g}}_i$. The values generated by operation of $\underset{\sim}{g}$ on $\underset{\sim}{x}$ form a matrix, $\hat{g}_{ij}$, corresponding to the ith element of $\underset{\sim}{g}$ and the jth member of the population. Then the notation $\underset{\sim}{\hat{g}}_{.j}$ denotes the column vector of values for all g functions for the jth population member, and the notation $\underset{\sim}{\hat{g}}_{i.}$ represents the row vector of values of the ith g function for all population members. A similar notation is extended to the function vectors $\underset{\sim}{z}$ and $\underset{\sim}{y}$; $\underset{\sim}{b}$ and $\underset{\sim}{r}$ parameter vectors may also have vector elements.

Introduction of the ability to cycle through a single subsystem a specified number of times, with each cycle processing in turn a member of a population of identically structured subsystems, required modification in the FLEX algorithm. Instead of incrementing k' automatically after each pass through the subsystem, counter k" is incremented after each pass and then checked against p. The population number, p, is set before a simulation run. If the subsystem has not been processed p times, then the g functions are called and the subsystem is processed again. The values $\underset{\sim}{\hat{g}}_{.j}$ are calculated, the updated values of $\underset{\sim}{x}_{.j}$ are obtained, and k" and j are incremented. After cycling p times, the vector elements of g and $\underset{\sim}{x}$ have been updated; k' is then incremented and the next pass through the g functions will fix $\underset{\sim}{\hat{g}}_{.1}$ before the first call to the subsystem for that time step.

Although complex, this procedure is straightforward. The matrix of state variables, $\underset{\sim}{X}$, is updated by column vectors and the values $\hat{\underset{\sim}{G}}$ are calculated by column vectors. It implies, however, that internal storage locations for the values $\hat{g}_{ij}$, x_{ij}, etc., are within the processor. These locations do not exist in the current processor version. Vector values must be stored on external files that are accessed, manipulated, and updated by the various functions and subroutines that use them.

The following procedure is used to implement this algorithm feature on the current processor version. At k' = 0, the g functions are called as usual. In a ghost module, each g_i, may operate in a different mode. A g_i may calculate $\hat{g}_{i.}$ at this time and store it on an external file. A g_i may calculate only a scalar value and have it available in the standard way for use by other g_i's. Or a g_i may be used to process external files, initialize the state variable and input variable matrices, and store them on external files for subsystem access. Each time the subsystem is processed, the functions within the subsystem reads ghost's $\hat{\underset{\sim}{g}}_{.j}$ from the file. The g functions in the subsystem generate only that subsystem's column vector $\hat{\underset{\sim}{g}}_{.j}$, and these values are stored in the processor and are accessed in the standard way. The subsystem's updated values of $\underset{\sim}{x}_{.j}$ are stored on a different external file, not in the ghost module. On completion of subsystem processing, the functions in the ghost module may then access those files as necessary.

The above procedure introduces a new level of complexity in FLEX programing. Much of this complexity could be avoided by introducing a new level in the hierarchy, but this entails difficulties as well as increasing processing time and cost. The approach used here is relatively inexpensive and easily implemented.

CORRESPONDENCE OF THE THREE MODEL VERSIONS

The model for interaction of the tussock moth larvae and host foliage was originally conceptualized and developed in terms of daily resolution mechanisms. Table 1 defines the daily resolution occasion structure of version 1.2. This model was restructured into the instar resolution of table 2 for version 2.2. Only one change in the conceptual structure is necessitated by this change in resolution. The model growth and feeding of the tussock moth is altered in the fourth instar to accommodate the convolution of larval growth with population survival over an instar. This is accomplished by assuming that the growth rate is constant throughout this instar, at the average of the two growth rates used during this instar in version 1.2. This changes the accumulating larval biomass, but only slightly and only during the fourth instar.

The organization of the models by subsystem and function identification is shown in table 3. The subsystems are those of the branch model at both daily and instar resolution. The g functions, although representing the same processes, do change form from version 1.2 to version 2.2. The details of the functional forms are given in the FLEXFORMS that follow.

The functions of version 2.2 are directly transferred into the branch model of module S_1 of version 3.1 (see figure 3). The only changes necessary are:

(i) some "normal tree" parameters are being brought in as z inputs rather than being internal b parameters;

(ii) the time index is changed from k to k';

(iii) the overwintering activities of occasion 10 of table 2 take place in the ghost module S_0 of version 3.1. The details of these changes are presented in the version 3.1 FLEXFORMS.

Table 1 --Douglas-fir tussock moth population-branch model, daily resolution form, Version 1.2. Occasion/time structure: note that occasion t is the interval before time k; k = t-1 during occasion t

Occasion	Description
Initiation	Bud burst and shoot elongation complete.
1	Egg hatch and establishment of first instars.
2	First day of feeding, growth, and mortality.
.	
.	
.	
10	Ninth day of feeding, growth, and mortality.
11	Last day larvae are in the first instar: feeding, growth, and mortality.
.	
.	
.	
21	Last day larvae are in the second instar: feeding, growth, and mortality.
.	
.	
.	
31	etc.
.	
.	
.	
41	etc.
.	
.	
.	
51	Last day larvae are in the fifth instar: feeding, growth, mortality, and male pupation.
.	
.	
.	
61	Last day of sixth instar: feeding, growth, mortality, and female pupation.
62	Pupal mortality and adult female emergence.
63	Eggs laid, aging of new foliage, and new foliage potential set. Redistribution of insects over the stand.[1/]
64	Overwinter mortality of foliage. Overwinter mortality of eggs.[2/]

[1/] This is not operative in a single-tree run, only in the stand-outbreak model.

[2/] Overwinter mortality accounts for all the mortality factors to which the egg masses are subjected between the time they are laid in the fall and hatch in the spring. In the current version, it also implicitly accounts for the mortality between hatching and establishment of first instars.

Table 2 --Douglas-fir tussock moth population-branch model instar resolution form, Version 2.2 and 3.1 (module S_1)

Occasion/time structure

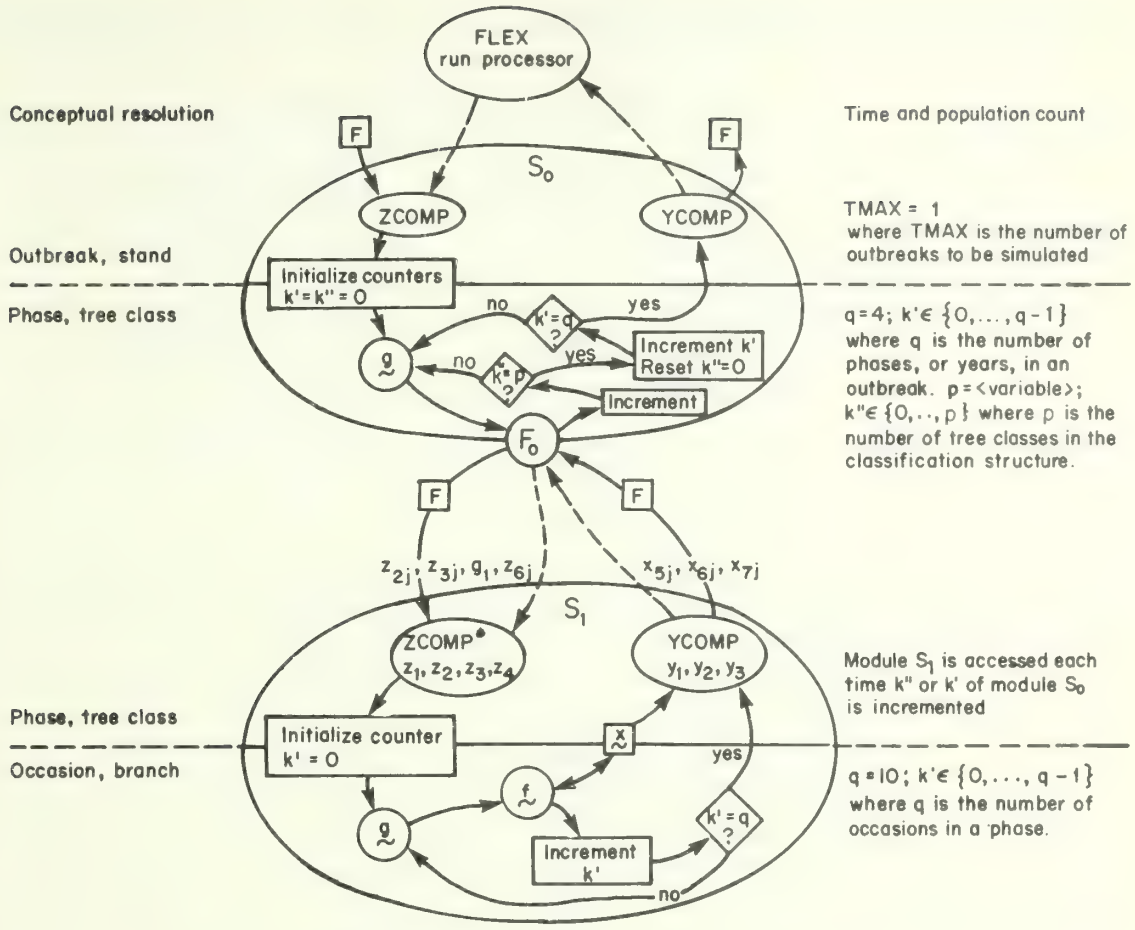
Occasion	Description
Initiation	Bud burst and shoot elongation complete.
1	Egg hatch, establishment on foliage.
2	First instars: feeding, growth, and mortality.
3	Second instars: feeding, growth, and mortality.
4	Third instars: feeding, growth, and mortality.
5	Fourth instars: feeding, growth, and mortality.
6	Fifth instars: feeding, growth, and mortality. Male pupation occurs after fifth-instar feeding.
7	Sixth instars (female): feeding, growth, mortality, and female pupation.
8	Pupal mortality and adult female emergence.
9	Eggs laid, aging of foliage, and new foliage potential set.
10	Redistribution of eggs.[1/] Overwinter mortality of foliage and overwinter mortality of eggs.

[1/] In Version 3.1, the events of occasion 10 take place in module S_0.

Table 3 --G function assignment by subsystems for the three model versions

Subsystems (S_j): 1. Foliage dynamics
2. Population dynamics
3. Growth and feeding

Subsystems	G Functions	Identity
	Versions 1.2 & 2.2 and Version 3.1 Lower Module	
S_1:	1, 4	New foliage destruction and production.
	2, 5	Old foliage destruction and (for V1 and V2) mortality.
	3	Aging of new foliage into old.
S_2:	6, 7, 8	Determination of daily larval mortality.
	9	Index of days spent feeding on old foliage.
	10	Fecundity or special occasion mortality.
	11	Total mortality (or egg production).
S_3:	12	Nominal larval growth rate.
	13	Achieved larval growth.
	14	Fecundity stress index.
	15, 16, 17, 18	Food demand and function for allocation of demand to new and old foliage.
	19	Index of day on which foliage was depleted by feeding.
	Version 3.1 Upper Module	
	1	Phase or year of the outbreak.
	2	Redistribution of insects over the stand.
	3	Old foliage mortality.
	4	Overwinter mortality of eggs.



*ZCOMP sets the values in S_1 of $b_1, \ldots, b_6, b_{34}, b_{35}, b_{36}$, and $r_1, \ldots, r_{12}$ according to the value of z_3, and $r_{13}, \ldots, r_{18}$ according to the value of z_4. Also, the values of x_{5j}, x_{6j}, and x_{7j} of S_o become the initial conditions for x_1, x_2, and x_3 of S_1, respectively, and x_4 of S_1 is initialized to zero.

F external file

Figure 3.--Stand-outbreak model, Version 3.1: Module stacking and sequencing. Note: The ovals marked ZCOMP and YCOMP represent the FLEX input and output variable processor subroutines, respectively, for each module. This figure follows the convention of figures 5 and 6 in White and Overton (1977). The F's in boxes are external data files used in data storage and module coupling. For details, see page 46. Couplings between S_0 and S_1 are given in terms of variables of S_0.

FLEXFORMS: V1.2; V2.2; V3.1 MODULE S_0; V3.1, MODULE S_1

FLEXFORM: V1.2 TITLE: DFTM Population-Branch Model, Version 1.2
Page 1 of 12

DATE: March 8, 1974 INVESTIGATORS: Overton, White, Hunt, Colbert
March 15, 1977 (revised)

TEMPORAL RESOLUTION: day, occasion; duration of run, one season.

SPATIAL RESOLUTION: the hypothetical model branch.

QUANTITIES MODELED: Biomass (dry weight) of foliage and larva, numbers of insects.

Note: Conceptually this model can be treated as one occasion in an annual resolution model, with the annual quantities:

1. Annual variables
   - (i) actual foliage complement
     - a) new foliage biomass
     - b) old foliage biomass
   - (ii) viable egg density
2. "Phase-specific" parameters
   - (i) egg-mass size
   - (ii) disease, parasite/predator mortality rates
   - (iii) overwinter egg and larval establishment mortality rates
3. Parameters that originate as "branch-outbreak" variables or parameters
   - (i) nominal foliage complements
   - (ii) Phase I initial viable egg density
   - (iii) host specific mortality rates
   - (iv) (host species)

SUBSYSTEMS:

1. Foliage dynamics
2. Population dynamics
3. Growth and feeding

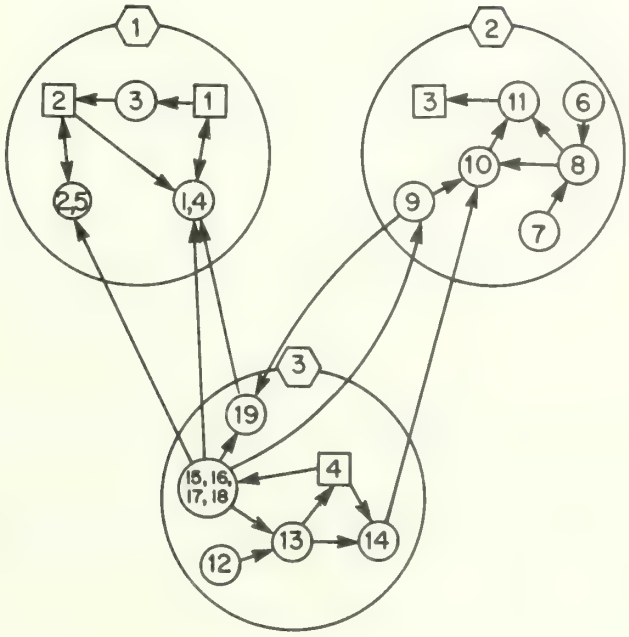
Symbol Key:

⬡ Subsystem designation.

◯ System, subsystem, process or function. Numbers in small circles are g function indices.

☐ State variables.

DIAGRAM:



VARIABLES AND FUNCTIONS

1. X List

Variable	Description	Units
x_1	New foliage biomass ($0 \leq k \leq 62$) and new foliage potential for the next year ($k = 63, 64$).	g
x_2	Old foliage biomass.	g
x_3	Viable eggs ($k = 0$). Established first instars ($k = 1$). Feeding larvae, male and female ($1 < k \leq 50$). Feeding female larvae ($51 \leq k \leq 60$). Female pupae ($k = 61$). Adult females emerged ($k = 62$). Viable eggs produced ($k = 63$). Viable eggs after overwinter mortality ($k = 64$).	number
x_4	Individual larval biomass.	mg
x_5	Individual larval biomass at $k = 36$.	mg

2. Z Functions

No inputs other than initial conditions are needed in this single-year version of the model. Phase-specific "inputs" are incorporated as parameters.

3. G Functions

Functional Form and Description — Units

$$g_1 = \begin{cases} \frac{b_{37}}{100} \cdot b_{38} \left[\frac{x_1 + x_2 + b_{38}}{2b_{38}} - g_{19} b_{32} \right] & \text{for } k = 62 \\ 0 & \text{otherwise.} \end{cases}$$

g

This function accounts for the capacity to produce new foliage (g-dryweight) after the completion of feeding by the DFTM ($k = 62$) and before the overwinter needle drop. If feeding results in total defoliation, then new foliage is reduced in proportion to the number of days of total defoliation (g_{19}).

Functional Form and Description — Units

$$g_2 = \begin{cases} \max\left[0,\ x_2 - b_{38}\left(1 - \frac{b_{37}}{100}\right)\right] & \text{for } k = 63, \\ 0 & \text{otherwise.} \end{cases}$$ g

Needle drop or litter production (g-dryweight) from the branch. This process is required to keep the branch in equilibrium under normal conditions.

$$g_3 = \begin{cases} x_1 \text{ for } k = 62, & \text{Aging of new foliage to old foliage.} \\ 0 \text{ otherwise.} \end{cases}$$ g

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$$g_4 = \begin{cases} \min(g_{16},\ x_1) & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases}$$ g

Destruction of new foliage (g-dryweight) for each day of feeding ($1 \leq k \leq 60$).

$$g_5 = \begin{cases} \min(g_{18} - g_4,\ x_2) & \text{for } 1 \leq k \leq 60 \text{ and } g_4 < g_{16}, \\ 0 & \text{otherwise.} \end{cases}$$ g

Destruction of old foliage (g-dryweight) for each day of feeding ($1 \leq k \leq 60$) for which demand for food can not be fully satisfied by feeding on new foliage.

$$g_6 = \begin{cases} (1 - r_{s_1})(1 - r_{s_1+6})(1 - b_{s_1}) & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases}$$ d^{-1}

The survivorship per day (d^{-1}) associated with disease mortality (r_{s_1}), predator and parasite mortality (r_{s_1+6}), and background mortality (b_{s_1}). Each is instar specific (see special function s_1).

Functional Form and Description — Units

$$g_7 = \begin{cases} 1 - r_{s_1} + 12 & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases}$$ Units: d^{-1}

The daily survivorship associated with stress from feeding on old foliage; instar specific.

$$g_8 = \begin{cases} g_6 g_7^{1-g_{15}} - 1 & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases}$$ Units: d^{-1}

Negative total daily mortality rate. [Assume $0^0 \equiv 1$.]

$$g_9 = \begin{cases} 0 & \text{for } k = 0 \text{ or } k = 63, \\ x_1^* + g_{17} & \text{otherwise.} \end{cases}$$ Units: d

(implicitly, $x_1^*(k+1) = x_1^*(k) + g_{17}(k)$)

Total number of days (d) spent feeding on old foliage during which demands are fully satisfied.

$$g_{10} = \begin{cases} -b_{39} & \text{for } k = 0, \\ -b_{34}(1 + g_8) & \text{for } k = 50, \\ -b_{26} & \text{for } k = 61, \\ b_{27}\, g_{14}(1 - b_{33} g_9) - 1 & \text{for } k = 62, \\ -b_{35} & \text{for } k = 63, \\ 0 & \text{otherwise.} \end{cases}$$ Units: number

This function accounts for changes in number of larvae from establishment mortality (k = 0), male pupation (k = 50), female pupal mortality (k = 61), viable eggs produced by the remaining females (k = 62), and overwinter mortality (k = 63). Fecundity is reduced in proportion to the number of days spent feeding on old foliage (g_9) and the final weight of the female larva (g_{14}).

Functional Form and Description		Units
$g_{11} = (g_8 + g_{10})x_3$	Larval mortality, male pupation, pupal mortality, egg production.	number
$g_{12} = \begin{cases} b_{22} & \text{for } 1 \le k \le 35, \\ b_{23} & \text{for } 36 \le k \le 60, \\ 0 & \text{for } x_3 \le 0 \text{ or } x_1 + x_2 \le 0 \text{ or } k = 0 \text{ or } k \ge 61. \end{cases}$	The nominal instantaneous larval growth rate. Larvae grow at the nominal rate as long as food is available.	d^{-1}
$g_{13} = \begin{cases} b_{25} & \text{for } k = 0, \\ x_4(e^{\phi g_{12}} - 1) & \text{for } 1 \le k \le 60, \\ 0 & \text{for } k \ge 61. \end{cases}$		mg

Here

$$\phi = \begin{cases} \dfrac{g_4 + g_5}{g_{15}g_{16} + g_{17}g_{18}} & \text{for } (g_{15} + g_{17}) \neq 0, \\ \dfrac{g_4 + g_5}{g_{18}} & \text{for } (g_{15} + g_{17}) = 0. \end{cases}$$

Achieved larval growth increment. The proportion ϕ is the ratio of actual foliage destruction to total foliage demand; if less than one, then the larvae did not feed for the full day and hence the growth is reduced according to the proportion ϕ.

$g_{14} = \max\left[\frac{2x4}{b_{24}} - 1, 0\right]$	Fecundity stress index, which is measured relative to the nominal final biomass (b_{24}).	none
$g_{15} = \begin{cases} 1 \text{ if } g_{16} < x_1 \text{ and } 1 \le k \le 60, \\ 0 \text{ otherwise.} \end{cases}$	The indicator of a day spent feeding exclusively on new foliage.	d

Functional Form and Description — Units

$$g_{16} = \begin{cases} b_{s_1} + 6 \left[\frac{10^{-3}}{b_{21}} (b_{19} + \frac{b_{20}}{g_{12}})(e^{g_{12}} - 1)\right] x_3 x_4 & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases}$$ g

New foliage demand for the day's feeding and growth.

$$g_{17} = \begin{cases} 1 \text{ if } g_{15} = 0, \\ \quad 1 \leq k \leq 60, \text{ and } (x_1 + x_2) > g_{18}, \\ 0 \text{ otherwise.} \end{cases}$$ d

The indicator of a day spent feeding on old foliage with demand completely satisfied.

$$g_{18} = \begin{cases} b_{s_1} + 12 \left[\frac{10^{-3}}{b_{21}} (b_{19} + \frac{b_{20}}{g_{12}})(e^{g_{12}} - 1)\right] x_3 x_4 & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases}$$ g

Old foliage demand for the day's feeding and growth.

$$g_{19} = \begin{cases} 60 - [x_2^* + g_9] & \text{for } k = 62, \\ 0 & \text{otherwise.} \end{cases}$$ d

(implicitly, $x_2^*(k+1) = x_2^*(k) + g_{15}(k)$)

Total number of days during the larval period for which food demands were not fully satisfied.

Functional Form and Description — Units

$$g_{20}\underline{4/} = \begin{cases} 0 & \text{for } k = 0,\ x_3 \le 0,\ x_1 + x_2 \le 0, \text{ or } k \ge 61, \text{ [1]} \\ b_{22} & \text{for } k = 1 \text{ or } [x_4 \ge (1 - b_{31})g_{21} \text{ and } 2 \le k \le 35], \text{ [2]} \\ \dfrac{\ell n(x_4/b_{25})}{k-1} & \text{for } x_4 < (1 - b_{31})g_{21} \text{ and } 2 \le k \le 35, \text{ [3]} \\ b_{23} & \text{for } k = 36 \text{ or } [x_4 \ge (1 - b_{31})g_{21} \text{ and } 37 \le k \le 60], \text{ [4]} \\ \dfrac{\ell n(x_4/x_5)}{k-36} & \text{for } x_4 < (1 - b_{31})g_{21} \text{ and } 37 \le k \le 60. \text{ [5]} \end{cases} \quad d^{-1}$$

The modified growth rate of an individual larva. [3] and [5] are growth rates for trajectories below the normal; [2] and [4] for normal trajectories.

$$g_{21}\underline{4/} = \begin{cases} b_{25}e^{b_{22}k} & \text{for } 0 \le k \le 35, \\ b_{25}e^{35b_{22} + (k - 35)b_{23}} & \text{for } 36 \le k \le 60, \\ b_{25}e^{35b_{22} + 25b_{23}} & \text{otherwise.} \end{cases} \quad mg$$

Nominal larval growth trajectory.

$$g_{22}\underline{4/} = \begin{cases} x_4 & \text{if } k = 36, \\ 0 & \text{otherwise.} \end{cases}$$

Larval biomass after 35 days of feeding, benchmark for determining reduced growth rate. — mg

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$$g_{23}\underline{4/} = \max\left\{2\left[\frac{x_4 + g_{13}}{g_{21}}\right] - 1,\ 0\right\}$$

Fecundity stress index. — none

4/ Note: These four g-functions are not operational, but are given here to exhibit how variable growth rates for the larvae might be implemented if additional food becomes available after foliage is depleted. The functions g_{20} and g_{23} would replace the present g_{12} and g_{14}, respectively.

4. F Functions

Functional Form and Description		Units
$f_{1,1} = g_1 - g_4$		g
$f_{1,2} = g_3$		g
$f_{2,2} = -g_5 - g_2$	See state variables X list, for	g
$f_{3,3} = g_{11}$	descriptions.	number
$f_{4,4} = g_{13}$		mg
$f_{5,5} = g_{22}$		mg

5. Y Functions

Functional Form and Description		Units
$y_i = x_i,$	$i = 1, 2, 3, 4$	See X list for descriptions and units.

6. Special Functions

Functional Form and Description		Units
s_1[5/] $= \left[\frac{k - 1}{10}\right] + 1$	The current instar of the population.	none

PARAMETERS

7. B Parameters

$b_1, \ldots, b_{22}$ identical to $b_1, \ldots, b_{22}$ of Version 2.2. See page 7, 8 of Version 2.2 FLEXFORM.

5/ Note: For this function, [x] is the largest integer that does not exceed the magnitude of x.

List	Value	Description	Units
b_{23}	0.0625	Instantaneous growth rate for $36 \leq k \leq 60$.	d^{-1}
b_{24}	52.063	Nominal biomass of female larvae at the end of the sixth instar, $k = 61$.	mg
b_{25}	0.197	Initial nominal biomass of larvae after establishment.	mg
b_{26}	I, .50; II, 0.62; III, .75; IV, .90	Phase-specific pupal mortality rate.	$occasion^{-1}$
b_{27}	I, 200; II, 200; III, 150; IV, 150.	Phase-specific nominal egg-mass size.	number
b_{28}	(not used)		
b_{29}	(not used)		
b_{30}	(not used)		
b_{31}	1.0×10^{-8}	Error tolerance in larval growth trajectory.	none
b_{32}	0.02	Coefficient of reduction in bud capacity from total branch defoliation.	d^{-1}
b_{33}	0.01	Coefficient of reduction in fecundity from feeding on old foliage.	d^{-1}
b_{34}	0.50	Proportion of larvae that are male at the end of the fifth instar.	none
b_{35}	I, .50; II, .60; III, .85; IV, .90.	Overwinter mortality.	$occasion^{-1}$
b_{36}	1, 2, 3 or 4	Phase index.	none
b_{37}[6/]		Nominal percent of new foliage.	none
b_{38}[6/]		Nominal total foliage biomass per model branch.	g
b_{39}	0.0	Phase-specific larval establishment mortality.	$occasion^{-1}$

6/ The values of b_{37} and b_{38} are chosen according to the properties of the host tree for a particular simulation.

8. R Parameters

List	Value					Description	Units
	I	II	III	IV	Instar		
r_1	0.0	0.0	0.002	0.025	1st	Instar and phase-specific daily disease mortality rate.	d^{-1}
r_2	0.0	0.0	0.003	0.028	2nd		
r_3	0.0	0.0	0.006	0.031	3rd		
r_4	0.0	0.0	0.013	0.034	4th		
r_5	0.0	0.001	0.035	0.035	5th		
r_6	0.0	0.001	0.028	0.035	6th		
r_7	0.0	0.0	0.001	0.005	1st	Instar- and phase-specific daily predator/parasite mortality rate.	d^{-1}
r_8	0.0	0.0	0.002	0.006	2nd		
r_9	0.0	0.0	0.003	0.007	3rd		
r_{10}	0.0	0.0	0.010	0.021	4th		
r_{11}	0.0	0.001	0.016	0.033	5th		
r_{12}	0.0	0.001	0.042	0.056	6th		

	Douglas-fir	Grand fir			
r_{13}	1.0	1.0	1st	Instar- and host-specific daily food stress mortality rate.	d^{-1}
r_{14}	0.75	0.8	2nd		
r_{15}	0.10	0.5	3rd		
r_{16}	0.0	0.1	4th		
r_{17}	0.0	0.0	5th		
r_{18}	0.0	0.0	6th		

9. Initial Conditions[7]

x_1	50.4
x_2	93.6
x_3	3.5
x_4	0.0

GENERAL RUN INFORMATION

TSTART = 0

TMAX = 64

q = 1

LP, DUMP[8]: All y's, all g's

LP, DUMP frequency: 1

RUN LOG: This version of the model was developed for documentation purposes and was run only to verify model output against V3.1.

Source code file: DAILY

FLEX3 overlay[9]: *DAILY

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[7] The full range of admissible initial conditions is available from the authors upon request.

[8] LP stands for "line printer". DUMP stands for "dump file", a file used for compact storage of the details of a simulation for later review or reconstruction.

[9] "Overlay" as used here is the machine-executable code, and is called an "absolute element" on some other computers.

FLEXFORM: V2.2
Page 1 of 11

TITLE: DFTM Population-Branch Model
Version 2.2

INVESTIGATORS: Overton, Colbert, White

DATE: December 1, 1975

March 15, 1977 (revised)

TEMPORAL RESOLUTION: instar, occasion; duration of run is one season

SPATIAL RESOLUTION: the hypothetical model branch

QUANTITIES MODELED: biomass (dry weight) of foliage and larvae;
number of insects

SUBSYSTEMS: 1. Foliage dynamics
2. Population dynamics
3. Growth and feeding

DIAGRAM:
(See the diagram on page 2 of Version 1.2 FLEXFORM.)

VARIABLES AND FUNCTIONS

1. X List

List	Description	Units
x_1	New foliage biomass	g
x_2	Old foliage biomass	g
x_3	Viable eggs, k = 0.	number
	Established first instars (k = 1).	
	Feeding larvae, male and female (k = 2, 3, 4, 5).	
	Feeding female larvae (k = 6).	
	Female pupae (k = 7).	
	Adult female moths (k = 8).	
	Viable eggs produced (k = 9).	
	Viable eggs after overwinter mortality (k = 10).	
x_4	Individual larval biomass	mg

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2. Z Functions

No inputs, other than initial conditions, are in this single-year version of the model. Phase-specific "inputs" are incorporated as parameters.

3. G Functions

Functional Form and Description[10/]	Units
$g_1 = \begin{cases} \frac{b_{31}b_{32}}{100}\left[\frac{x_1 + x_2 + b_{32}}{2b_{32}} - g_{19}b_{27}\right] & \text{for } k = 8, \\ 0 & \text{otherwise.} \end{cases}$	g
New foliage capacity.	
$g_2 = \begin{cases} \max\left[0,\ x_2 - b_{32}\left(1 - \frac{b_{31}}{100}\right)\right] & \text{for } k = 9, \text{ Needle drop.} \\ 0 & \text{otherwise.} \end{cases}$	g
$g_3 = \begin{cases} x_1 & \text{for } k = 8, \\ 0 & \text{otherwise.} \end{cases}$ Aging of new foliage.	g
$g_4 = \begin{cases} \min(g_{16},\ x_1) & \text{for } 1 \leq k \leq 6, \\ 0 & \text{otherwise.} \end{cases}$ Destruction of new foliage.	g
$g_5 = \begin{cases} \min(g_{18},\ x_2) & \text{for } 1 \leq k \leq 6, \\ 0 & \text{otherwise.} \end{cases}$ Destruction of old foliage.	g

[10/] For more complete descriptions see Version 1.2 FLEXFORM.

Functional Form and Description — Units

$$g_6 = \begin{cases} (1 - r_k)(1 - r_{k+6})(1 - b_k) & \text{for } 1 \le k \le 6, \\ 0 & \text{otherwise.} \end{cases}$$ d^{-1}

Daily survivorship after disease, predator/parasite, and background mortality.

$$g_7 = \begin{cases} 1 - r_{k+12} & \text{for } 1 \le k \le 6, \\ 0 & \text{otherwise.} \end{cases}$$ d^{-1}

Daily survivorship after food stress.

$$g_8 = \begin{cases} g_6^{10}\, g_7^{10-g_{15}} - 1 & \text{for } 1 \le k \le 6, \\ 0 & \text{otherwise.} \end{cases}$$ none

Negative total mortality rate for an instar. [Assume $0^0 \equiv 1$.]

$$g_9 = \begin{cases} 0 & \text{for } k = 0 \text{ or } 9, \\ x_1^* + g_{17} & \text{otherwise.} \end{cases}$$ d

(Implicitly, $x_1^*(k + 1) = x_1^*(k) + g_{17}(k)$)

Total number of days spent feeding on old foliage during which demand is fully satisfied.

Special Occasion Processes:

$$g_{10} = \begin{cases} -b_{36} & \text{for } k = 0, \text{ Establishment mortality.} \\ -b_{30}(1 + g_8) & \text{for } k = 5, \text{ Male pupation.} \\ -b_{34} & \text{for } k = 7, \text{ Female pupal mortality.} \\ b_{35} g_{14}(1 - b_{28} g_9) - 1 & \text{for } k = 8, \text{ Viable eggs produced.} \\ -b_{37} & \text{for } k = 9, \text{ Overwinter mortality.} \\ 0 & \text{otherwise.} \end{cases}$$ none

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Functional Form and Description		Units
$g_{11} = (g_8 + g_{10})x_3$	Larval mortality, male pupation, pupal mortality, egg production, and overwinter mortality.	number
$g_{12} = \begin{cases} 0 & \text{for } x_3 \leq 0, \\ & (x_1 + x_2) \leq 0, \text{ or } k > 6, \\ b_{22} & \text{for } 1 \leq k < 4, \\ b_{23} & \text{for } k = 4, \\ b_{24} & \text{for } 4 < k \leq 6. \end{cases}$	Instantaneous daily growth rate.	d^{-1}
$g_{13} = \begin{cases} b_{25} & \text{for } k = 0, \\ x_4(e^{[10\phi g_{12}]} - 1) & \text{for } 1 \leq k \leq 6, \\ 0 & \text{for } k > 6, \end{cases}$ where $\phi = \left[\frac{g_4 + g_5}{g_4 + g_{18}}\right]$	Achieved larval growth increment for an instar. The proportion ϕ is the ratio of actual needle destruction to total needle demand; if less than one, the larvae did not feed all 10 days, and the number of days spent growing is reduced according to the proportion ϕ.	mg
$g_{14} = \max\left[\frac{2x_4}{b_{26}} - 1, 0\right]$	Fecundity stress index.	none
$g_{15} = \begin{cases} \alpha & \text{where } \alpha \in \{0, 1, \ldots, 10\} \text{ is the largest integer such that } UV1(k, x, b, \alpha) < x_1, \\ 0 & \text{for } k = 0 \text{ or } k > 6 \text{ or if no } \alpha \text{ exists that satisfies the above inequity.} \end{cases}$	Time spent feeding exclusively on new foliage.	d

Functional Form and Description	Units

$$g_{16} = \begin{cases} \text{UV1}(k, \underset{\sim}{x}, \underset{\sim}{b}, \min[g_{15} + 1, 10]) \\ \qquad \text{for } x_1 > 0 \text{ and } 1 \leq k \leq 6, \\ 0 \qquad \text{otherwise.} \end{cases}$$ g

Total new foliage demand.

$$g_{17} = \begin{cases} \eta & \text{where } \eta \in \{0, 1, \ldots, 10 - g_{15}\} \\ & \text{is the smallest integer such that} \\ & [\text{UV2}(k, \underset{\sim}{x}, \underset{\sim}{b}, g_{15}, \eta + 1) - \\ & (x_1 - \text{UV1}(k, \underset{\sim}{x}, \underset{\sim}{b}, g_{15}))] > x_2 \text{ and} \\ 10 - g_{15} & \text{otherwise for } 1 \leq k \leq 6, \\ 0 & \text{for } k = 0 \text{ or } k > 6. \end{cases}$$ d

The number of days spent feeding on old foliage for which demand is fully satisfied.

$$g_{18} = \begin{cases} \max[\text{UV2}(k, \underset{\sim}{x}, \underset{\sim}{b}, g_{15}, 10 - g_{15}) - \\ (x_1 - \text{UV1}(k, \underset{\sim}{x}, \underset{\sim}{b}, g_{15})), & \text{for } 1 \leq k \leq 6, \\ 0 & \text{for } k = 0 \text{ or } k > 6. \end{cases}$$ g

Total old foliage demand for remainder of the instar.

$$g_{19} = \begin{cases} 0 & \text{for } k = 0 \text{ or } 9, \\ x_2^* & \text{for } k = 7 \text{ or } 8, \\ x_2^* + 10 - [g_{15} + g_{17}] & \text{otherwise.} \end{cases}$$ g

(Implicitly, $x_2^*(k + 1) = x_2^*(k) + 10 - [g_{15}(k) + g_{17}(k)]$).

Total number of days during which demand for food is not fully satisfied.

4. F Functions

Functional Form and Description		Units
$f_{1,1} = g_1 - g_4$	See state variables, X list, for descriptions.	g
$f_{1,2} = g_3$		g
$f_{2,2} = -g_5 - g_2$		g
$f_{3,3} = g_{11}$		number
$f_{4,4} = g_{13}$		mg

5. Y Functions

$y_i = x_i$, $i = 1, 2, 3, 4$ See X list for description and units.

6. Special Functions

Functional Form and Description — Units

$UV1(k, \underset{\sim}{x}, \underset{\sim}{b}, \alpha) = U(\underset{\sim}{x}, \underset{\sim}{b}, k) \cdot V_1(\underset{\sim}{b}, \alpha, k)$, g

where

$$U(\underset{\sim}{x}, \underset{\sim}{b}, k) = \frac{10^{-3}}{b_{21}} \left[b_{19} + \frac{b_{20}}{g_{12}} \right] (e^{g_{12}} - 1) x_3 x_4,$$

$$V_1(\underset{\sim}{b}, \alpha, k) = b_{6+k} \frac{1 - \left[g_6 e^{g_{12}} \right]^{\alpha}}{1 - g_6 e^{g_{12}}},$$

and

$UV1 = 0$ for $k \notin \{ 1, \ldots, 6 \}$.

Total new foliage demand for an instar. U is the food demand for metabolism and growth, V_1 is the product of the destruction/consumption ratio and the convolution of daily larval growth and daily larval survivorship during feeding on new foliage. See g_{14} and g_{15}.

Functional Form and Description — Units

$$UV2(k, \underset{\sim}{x}, \underset{\sim}{b}, \alpha, \eta) = U(\underset{\sim}{x}, \underset{\sim}{b}, k) \cdot V_2(\underset{\sim}{b}, \alpha, \eta, k). \qquad g$$

where U is given in UV1 above

and

$$V_2(\underset{\sim}{b}, \alpha, \eta, k) = b_{12+k} g_6^{\alpha} e^{\alpha g_{12}} \left[\frac{1 - \left[g_6 g_7 e^{g_{12}} \right]^{\eta}}{1 - \left[g_6 g_7 e^{g_{12}} \right]} \right]$$

$$UV2 = 0 \text{ for } k \notin \{ 1, \ldots, 6 \}$$

Total old foliage demand for an instar. U is the food demand for metabolism and growth, V_2 is the product of the destruction/consumption ratio with the convolution of the daily larval growth and daily larval survivorship during feeding on old foliage.

PARAMETERS

7. B Parameters

List	Value	Instar	Description	Units
b_1	0.02	1st	Instar-specific background daily mortality rate.	d^{-1}
b_2	0.02	2nd		
b_3	0.02	3rd		
b_4	0.02	4th		
b_5	0.02	5th		
b_6	0.02	6th		
b_7	5.4	1st	Instar-specific destruction/consumption ratio for feeding on new foliage.	none
b_8	6.25	2nd		
b_9	6.25	3rd		
b_{10}	2.71	4th		
b_{11}	2.27	5th		
b_{12}	2.0	6th		
b_{13}	5.4	1st	Instar-specific destruction/consumption ratio for feeding on old foliage.	none
b_{14}	6.25	2nd		
b_{15}	6.25	3rd		
b_{16}	3.69	4th		
b_{17}	3.29	5th		
b_{18}	3.0	6th		

List	Value	Description	Units
b_{19}	1.19	Assimilated food, growth coefficient.	none
b_{20}	0.081	Assimilated food, respiration coefficient.	d^{-1}
b_{21}	0.10	Assimilation efficiency.	none
b_{22}	0.1147	Instantaneous growth rate for first three instars.	d^{-1}
b_{23}	0.0886	Instantaneous growth rate for fourth instar.	d^{-1}
b_{24}	0.0625	Instantaneous growth rate for fifth and sixth instars.	d^{-1}
b_{25}	0.197	Initial biomass of larvae at hatch.	mg
b_{26}	52.063	Nominal biomass of female larvae at the end of the sixth instar.	mg
b_{27}	0.02	Coefficient of reduction in bud capacity from total branch defoliation.	d^{-1}
b_{28}	0.01	Coefficient of reduction in fecundity from feeding on old foliage.	d^{-1}
b_{29}	1,2,3,4	Phase index.	none
b_{30}	0.50	Proportion of larvae that are male at the end of the fifth instar.	none
b_{31} [11/]		Nominal percent new foliage.	none
b_{32} [11/]		Nominal total foliage biomass.	g
b_{33}	(not used)		
b_{34}	I:0.50; II:0.62; III:0.75; IV:0.80	Phase-specific pupal mortality rate.	$occasion^{-1}$
b_{35}	I,II:200; III,IV:150.	Phase-specific maximum egg-mass size.	number
b_{36}	I,II,III, IV:0.0	Phase-specific establishment mortality rate.	$occasion^{-1}$
b_{37}	I:0.50; II:0.60; III:0.85; IV:0.90	Phase-specific overwinter mortality rate.	$occasion^{-1}$

11/ Note: b_{31} and b_{32} have values that depend on the host tree being simulated and are chosen, accordingly, prior to a specific simulation.

8. R Parameters

List	Value - Phase - I	II	III	IV	Instar	Description	Units
r_1	0.0	0.0	0.002	0.025	1st	Instar- and phase-specific daily disease mortality rate	d^{-1}
r_2	0.0	0.0	0.003	0.028	2nd		
r_3	0.0	0.0	0.006	0.031	3rd		
r_4	0.0	0.0	0.013	0.034	4th		
r_5	0.0	0.001	0.035	0.035	5th		
r_6	0.0	0.001	0.028	0.035	6th		
r_7	0.0	0.0	0.001	0.005	1st	Instar- and phase-specific daily predator/parasite mortality rate	d^{-1}
r_8	0.0	0.0	0.002	0.006	2nd		
r_9	0.0	0.0	0.003	0.007	3rd		
r_{10}	0.0	0.0	0.010	0.021	4th		
r_{11}	0.0	0.001	0.016	0.033	5th		
r_{12}	0.0	0.001	0.042	0.056	6th		
	Douglas-fir		grand fir				
r_{13}	1.0		1.0		1st	Instar- and host-specific daily food-stress mortality rate.	d^{-1}
r_{14}	0.75		0.8		2nd		
r_{15}	0.10		0.5		3rd		
r_{16}	0.0		0.1		4th		
r_{17}	0.0		0.0		5th		
r_{18}	0.0		0.0		6th		

9. Initial Conditions[12/]

x_1 50.4
x_2 93.6
x_3 75.0
x_4 0.0

GENERAL RUN INFORMATION

TSTART = 0

TMAX = 10

q = 1

LP, DUMP: All y's; all g's

LP, DUMP frequency: 1

RUN LOG: This version of the model was developed for the purpose of documentation and was run only to verify this model form against V3.1. See appendix B for verification output.

Source code file: INSTAR

FLEX3 overlay: *INSTAR

12/ These initial conditions, along with the phase II b and r parameters for grand fir, were used to develop the appendix B verification output.

FLEXFORM: V3.1
MODULE: S_0
Page 1 of 7

TITLE: DFTM Stand-Outbreak Model Version 3.1

Outbreak/Stand Module.

INVESTIGATORS: Overton, Colbert, White

DATE: September 17, 1976

March 15, 1977 (revised)

TEMPORAL RESOLUTION: Outbreak/phase.

SPATIAL RESOLUTION: Stand (by tree class).

QUANTITIES MODELED: Biomass (dry weight) of foliage and larvae, number of insects per model branch, for each tree class.

DIAGRAM: See figure 3.

VARIABLES AND FUNCTIONS

1. X List

List	Phase	Description	Units
x_1	I	Weighted mean number of eggs per model branch over the tree classes of the stand.	number
x_2	II		
x_3	III		
x_4	IV		

The vector variables below contain an element for each tree class:

$\underset{\sim}{x}_5$	Actual new foliage potential (on entry to S_1). Actual new foliage biomass (on exit from S_1).	g
$\underset{\sim}{x}_6$	Actual total foliage biomass (on entry to S_1). Actual old foliage biomass (on exit from S_1).	g
$\underset{\sim}{x}_7$	Number of viable eggs.	number

---

2. Z Functions[13/]

List		Units
z_1	The number of tree classes in the stand for the current model run. This number is entered by the user **during** a model run. This value is stored in b_{57} for use in computing the final weighted mean number of eggs. This is also the value of p in the input command file and must be set **before** a model run.	number

The vector variables below contain an element for each tree class:

$\underset{\sim}{z}_2$	Nominal percent new foliage.	none
$\underset{\sim}{z}_3$	Nominal total foliage biomass.	g
$\underset{\sim}{z}_4$	Number of trees.	number
$\underset{\sim}{z}_5$	Weighting factor.	none
$\underset{\sim}{z}_6$	Host species (1 = Douglas-fir, 2 = grand fir).	none

3. G Functions

Functional Form and Description		Units
$g_1 = k' + 1$	Phase index.	number
g_{2j}[14/] $= \begin{cases} x_{7j} + b_{62}(x_{k'} - x_{7j}) & \text{for } k' > 0, \\ 0 & \text{otherwise.} \end{cases}$		none

Redistribution of viable eggs over the stand. (Implemented by a call to special function REDIST.)

[13/] Note: the z values are entered by the user in specifying a stand-outbreak model run.

[14/] Functions g_2, g_3, and g_4 process all tree classes on the first pass through the g functions each phase.

Functional Form and Description	Units
g_{3j} 14/ $= \begin{cases} \min[x_{6j}, z_{3j}(1 - z_{2j}/100)] & \text{for } k' > 0, \\ 0 & \text{otherwise.} \end{cases}$	g
Old foliage survivorship.	
g_{4j} 14/ $= \begin{cases} (1 - b_{56+g_1})g_{2j} & \text{for } k' > 0, \\ 0 & \text{otherwise.} \end{cases}$	number
Overwinter survival of eggs.	

4. Y Functions

YCOMP calls REDIST for computation of the mean fall egg density over the stand after phase IV. No y functions, per se, are included in this module. Instead, YCOMP accesses certain special functions to produce specially formatted output tables. These are documented elsewhere (see: Logical Unit Manipulation by User-Specified Functions).

5. Special Functions

Subroutine REDIST(k', n, $\underset{\sim}{b}$, $\underset{\sim}{x}$)

This subroutine first computes the mean egg density over the stand as follows:

$$x_{k'} = \frac{1}{T} \sum_{j=1}^{N} z_{4j} z_{5j} x_{7j}(k'),$$

where

$$T = \sum_{j=1}^{N} z_{4j} z_{5j}$$

and N is the number of tree classes; z_{4j} is the number of trees in the jth tree class; z_{5j} is the weight associated with a tree of the jth tree class; x_{7j} is the number of viable eggs laid for the jth tree class; and $x_{k'}$ is the fall mean egg density over the stand in phase k'.

The subroutine then redistributes the eggs over the stand according to $\underset{\sim}{g}_2$.

PARAMETERS

6. B Parameters

	Value	Instar	Phase	Description	Units
b_1	0.0	1st	I	Instar-specific disease mortality rate. (r_1, ..., r_6 in Version 2.2)	d^{-1}
b_2	0.0	2nd			
b_3	0.0	3rd			
b_4	0.0	4th			
b_5	0.0	5th			
b_6	0.0	6th			
b_7	0.0	1st	II		
b_8	0.0	2nd			
b_9	0.0	3rd			
b_{10}	0.0	4th			
b_{11}	0.001	5th			
b_{12}	0.001	6th			
b_{13}	0.002	1st	III		
b_{14}	0.003	2nd			
b_{15}	0.006	3rd			
b_{16}	0.013	4th			
b_{17}	0.035	5th			
b_{18}	0.028	6th			
b_{19}	0.025	1st	IV		
b_{20}	0.028	2nd			
b_{21}	0.031	3rd			
b_{22}	0.034	4th			
b_{23}	0.035	5th			
b_{24}	0.035	6th			
b_{25}	0.0	1st	I	Instar-specific predator/parasite mortality rates. (r_7, ..., r_{12} in Version 2.2)	d^{-1}
b_{26}	0.0	2nd			
b_{27}	0.0	3rd			
b_{28}	0.0	4th			
b_{29}	0.0	5th			
b_{30}	0.0	6th			
b_{31}	0.0	1st	II		
b_{32}	0.0	2nd			
b_{33}	0.0	3rd			
b_{34}	0.0	4th			
b_{35}	0.001	5th			
b_{36}	0.001	6th			

(continued)

	Value	Instar	Phase	Description	Units
b_{37}	0.001	1st			
b_{38}	0.002	2nd			
b_{39}	0.003	3rd			
b_{40}	0.010	4th	III		
b_{41}	0.016	5th			
b_{42}	0.042	6th			
b_{43}	0.005	1st			
b_{44}	0.006	2nd			
b_{45}	0.007	3rd			
b_{46}	0.021	4th	IV		
b_{47}	0.033	5th			
b_{48}	0.056	6th			
b_{49}	0.50		I	Pupal mortality rate. (b_{34} in Version 2.2)	occasion^{-1}
b_{50}	0.62		II		
b_{51}	0.75		III		
b_{52}	0.80		IV		
b_{53}	200		I	Maximum egg-mass size eggs/mass (b_{35} in Version 2.2)	number
b_{54}	200		II		
b_{55}	150		III		
b_{56}	150		IV		
b_{57}	--	Number of tree classes (see z functions)			number
			Phase		
b_{58}	0.50		I	Overwinter mortality rate. (b_{37} in Version 2.2)	occasion^{-1}
b_{59}	0.60		II		
b_{60}	0.85		III		
b_{61}	0.90		IV		
b_{62}	0.0	Redistribution dispersal factor			none
b_{63}	0.0		I	Establishment mortality rate. (b_{36} in Version 2.2)	occasion^{-1}
b_{64}	0.0		II		
b_{65}	0.0		III		
b_{66}	0.0		IV		

7. R Parameters

	Value	Instar	Description	Units
r_1	1.0	1st	Instar-specific daily food stress[15] mortality rates for Douglas-fir host species. (r_{13}, ..., r_{18} in Version 2.2)	none
r_2	0.75	2nd		
r_3	0.10	3rd		
r_4	0.0	4th		
r_5	0.0	5th		
r_6	0.0	6th		
r_7	1.0	1st	Instar-specific daily food stress[15] mortality rates for the grand fir host species. (r_{13}, ..., r_{18} in Version 2.2)	none
r_8	0.8	2nd		
r_9	0.5	3rd		
r_{10}	0.1	4th		
r_{11}	0.0	5th		
r_{12}	0.0	6th		
r_{13}	0.02	1st	Instar-specific daily background mortality rate. (b_1, ..., b_6 in Version 2.2)	none
r_{14}	0.02	2nd		
r_{15}	0.02	3rd		
r_{16}	0.02	4th		
r_{17}	0.02	5th		
r_{18}	0.02	6th		

8. Initial Conditions

See appendix C for an example of the specification of initial conditions.

[15] Stress from feeding on old foliage during early instars.

GENERAL RUN INFORMATION

Module Sequence Number = 0

TMAX = 1 q = 4

Module type: ghost

Variables to be monitored: none.

Variables to be dump filed: none.

FILE NAMES

FLEX2 function overlay name: *V31SO

Source file name: V31SO

COMMENTS

Model behavior will be documented in a separate paper. A record of the model runs made in studying behavior will be included therein. Appendix A contains the source code for Version 3.1 and the command file for initializing a simulation. Appendix C contains the inputs and outputs from a verification simulation.

FLEXFORM: V3.1 TITLE: DFTM Stand-Outbreak Model,

MODULE: S_1 Version 3.1, Tree/Branch Module

 INVESTIGATORS: Overton, Colbert, White

DATE: September 17, 1976

March 15, 1977 (revised)

TEMPORAL RESOLUTION: Phase/instar, occasion.

SPATIAL RESOLUTION: Tree class/hypothetical model branch.

QUANTITIES MODELED: Biomass (dry weight) of foliage and larvae, number of insects.

SUBSYSTEMS: 1. Foliage dynamics

2. Population dynamics

3. Growth and feeding

DIAGRAM:

(See the diagram on page 2 of Version 1.2 FLEXFORM.)

VARIABLES AND FUNCTIONS

1. X List

List	Description	Units
x_1	New foliage biomass (k' = 0, ..., 8). New foliage potential for next year (k' = 9, 10).	g
x_2	Old foliage biomass.	g
x_3	Viable eggs (k' = 0). Larvae (k' = 1, ..., 5). Female larvae (k' = 6). Female pupae (k' = 7). Adult female moths (k' = 8). Viable eggs produced (k' = 9, 10).	number
x_4	Individual larval biomass.	mg

---

2. Input Variables

Z Functions

Functional Form	Description	Units
$z_1 = z_{2j}$ in S_0	Nominal percent new foliage.	none
$z_2 = z_{3j}$ in S_0	Nominal total foliage biomass.	g
$z_3 = g_1$ in S_0	Phase index.	none
$z_4 = z_{6j}$ in S_0	Host species index.	none

Parameter Assignments

B Parameters

$[b_1, \ldots, b_6] = [r_{13}, \ldots, r_{18}]$ in S_0, respectively, for $z_3 = 1, 2, 3, 4$.

Value, Description, and Units

See V3.1 FLEXFORM, Module S_0, for the values, descriptions, and units of the assigned b and r parameters.

$$b_{34} = \begin{cases} b_{49} \text{ in } S_0 \text{ if } z_3 = 1, \\ b_{50} \text{ in } S_0 \text{ if } z_3 = 2, \\ b_{51} \text{ in } S_0 \text{ if } z_3 = 3, \\ b_{52} \text{ in } S_0 \text{ if } z_3 = 4. \end{cases}$$

$$b_{35} = \begin{cases} b_{53} \text{ in } S_0 \text{ if } z_3 = 1, \\ b_{54} \text{ in } S_0 \text{ if } z_3 = 2, \\ b_{55} \text{ in } S_0 \text{ if } z_3 = 3, \\ b_{56} \text{ in } S_0 \text{ if } z_3 = 4. \end{cases}$$

$$b_{36} = \begin{cases} b_{63} \text{ in } S_0 \text{ if } z_3 = 1, \\ b_{64} \text{ in } S_0 \text{ if } z_3 = 2, \\ b_{65} \text{ in } S_0 \text{ if } z_3 = 3, \\ b_{66} \text{ in } S_0 \text{ if } z_3 = 4. \end{cases}$$

R Parameters

$$[r_1, \ldots, r_6] = \begin{cases} [b_1, \ldots, b_6] & \text{in } S_0, \text{ respectively, for } z_3 = 1, \\ [b_7, \ldots, b_{12}] & \text{in } S_0, \text{ respectively, for } z_3 = 2, \\ [b_{13}, \ldots, b_{18}] & \text{in } S_0, \text{ respectively, for } z_3 = 3, \\ [b_{19}, \ldots, b_{24}] & \text{in } S_0, \text{ respectively, for } z_3 = 4. \end{cases}$$

$$[r_7, \ldots, r_{12}] = \begin{cases} [b_{25}, \ldots, b_{30}] & \text{in } S_0, \text{ respectively, for } z_3 = 1, \\ [b_{31}, \ldots, b_{36}] & \text{in } S_0, \text{ respectively, for } z_3 = 2, \\ [b_{37}, \ldots, b_{42}] & \text{in } S_0, \text{ respectively, for } z_3 = 3, \\ [b_{43}, \ldots, b_{48}] & \text{in } S_0, \text{ respectively, for } z_3 = 4. \end{cases}$$

$$[r_{13}, \ldots, r_{18}] = \begin{cases} [r_1, \ldots, r_6] & \text{in } S_0, \text{ respectively, for } z_4 = 1, \\ [r_7, \ldots, r_{12}] & \text{in } S_0, \text{ respectively, for } z_4 = 2. \end{cases}$$

---

3. G Functions

$g_1, \ldots, g_{19}$ are the same as in model Version 2.2, except that g_2 and the portion of g_{10} accounting for occasion 10(k=9) have been moved to the upper module and the following substitutions have been made:

Version 2.2	Version 3.1, S_1
b_{31}	z_1
b_{32}	z_2
b_{29}	z_3

Because processing in this module takes place using the lower level, k is replaced by k' in all of the g functions.

---

4. F Functions[16/]

Functional Form and Description		Units
$f_{1,1} = 10(g_1 - g_4)$		g
$f_{1,2} = 10g_3$	See state variables,	g
$f_{2,2} = -10g_5$	X List, for description	g
$f_{3,3} = 10g_{11}$	by corresponding indexes.	number
$f_{4,4} = 10g_{13}$		mg

5. Y Functions

$y_i = x_i$, $i = 1, 2, 3$ See X list for description and units.

6. Special Functions

The special functions UV1 and UV2 are the same as those used in Version 2.2 except that k in the call string has been replaced by k'.

PARAMETERS

For values and definitions, see Version 2.2 FLEXFORM.

7. B Parameters

List	Description
$b_1, \ldots, b_6$	Carried in S_0 and assigned as a variable input.
$b_7, \ldots, b_{12}$ $b_{13}, \ldots, b_{18}$ $b_{19}, \ldots, b_{30}$ b_{34}, b_{35}, b_{36}	As in Version 2.2 FLEXFORM.

16/ Because q = 10 for this module, each update is multiplied by 10 to nullify the automatic division by q (see Abstract of the FLEX Convention for further discussion).

8. R Parameters

$r_1, \ldots, r_6$
$r_7, \ldots, r_{12}$
$r_{13}, \ldots, r_{18}$

Carried in S_0 and assigned as a variable input.

---

9. Initial Conditions

See appendix C for an example of the specification of initial conditions.

GENERAL RUN INFORMATION

Module Sequence Number = 1.

TMAX = 1 q = 10 TARGET

Module type: terminal.

Variables to be monitored: y_1, y_2, y_3. Resolution: 1.

Variables to be dump filed: y_1, y_2, y_3. Resolution: 1.

FILE NAMES

FLEX2 function overlay name: *V31S1.

Source File name: V31S1.

COMMENTS

Model behavior will be documented in a separate paper. A record of the model runs made in studying behavior will be included therein. Appendix A contains the source code for version 3.1 and the command file for beginning a simulation. Appendix C contains the inputs and outputs from a verification simulation.

LOGICAL UNIT MANIPULATION BY USER-SPECIFIED FUNCTIONS

The DFTM stand-outbreak model, V3.1, makes extensive utilization of logical units (LUNs) in storing various vector values and in producing specially formatted output tables. Much of the information concerning these LUNs is summarized in table 4 and figure 4. This section details the information stored on some of the LUNs and the user specified functions that produce that information.

Table 4. Logical units: assignment list
Note: All LUNs are equipped as linear access files except LUN 25, which is a random access file.

Logical Unit Number (LUN)	Description	Data Format
1	Phase I initial conditions	(I2, 7F11.5, I3)
2	Phase I outputs	(3F12.6)
3	Phase I redistributed insects	(1F12.6)
4	Phase II initial conditions	(I2, 7F11.5, I3)
5	Phase II outputs	(3F12.6)
6	Phase II redistributed insects	(IF12.6)
7	Phase III initial conditions	(I2, 7F11.5, I3)
8	Phase III outputs	(3F12.6)
9	Phase III redistributed insects	(1F12.6)
10	Phase IV initial conditions	(I2, 7F11.5, I3)
11	Phase IV outputs	(3F12.6)
12	Phase IV redistributed insects	(1F12.6)
13	Mortality and top-kill for Douglas-fir host species	(1F7.4, 6F6.3)
14	Mortality and top-kill for grand fir	(1F7.4, 6F6.3)
15	*Table* 1: Insect-foliage outbreak summary	variable BCD
16	*Table* 2: Foliage-stand outbreak summary	variable BCD
17	*Table* 3: Simulation run model parameterization	variable BCD
18	Screen display format of *table* 1	variable BCD
19	Scratch pad for temporary storage of module S_0 function g_3 output values ($\hat{g}_3$.)	(1F12.6)
20	*Table* 4: (optional) detail output of state variables during each phase	variable BCD
21	State variable values at each occasion for each tree class and phase in a simulation	(4(2X, F14.7))
22	Screen display format of *table* 2: part I	variable BCD
23	Screen display format of *table* 2: part II	variable BCD
24	Screen display format of *table* 2: part II	variable BCD
25	State-variable values: input file for table 4 generation	binary

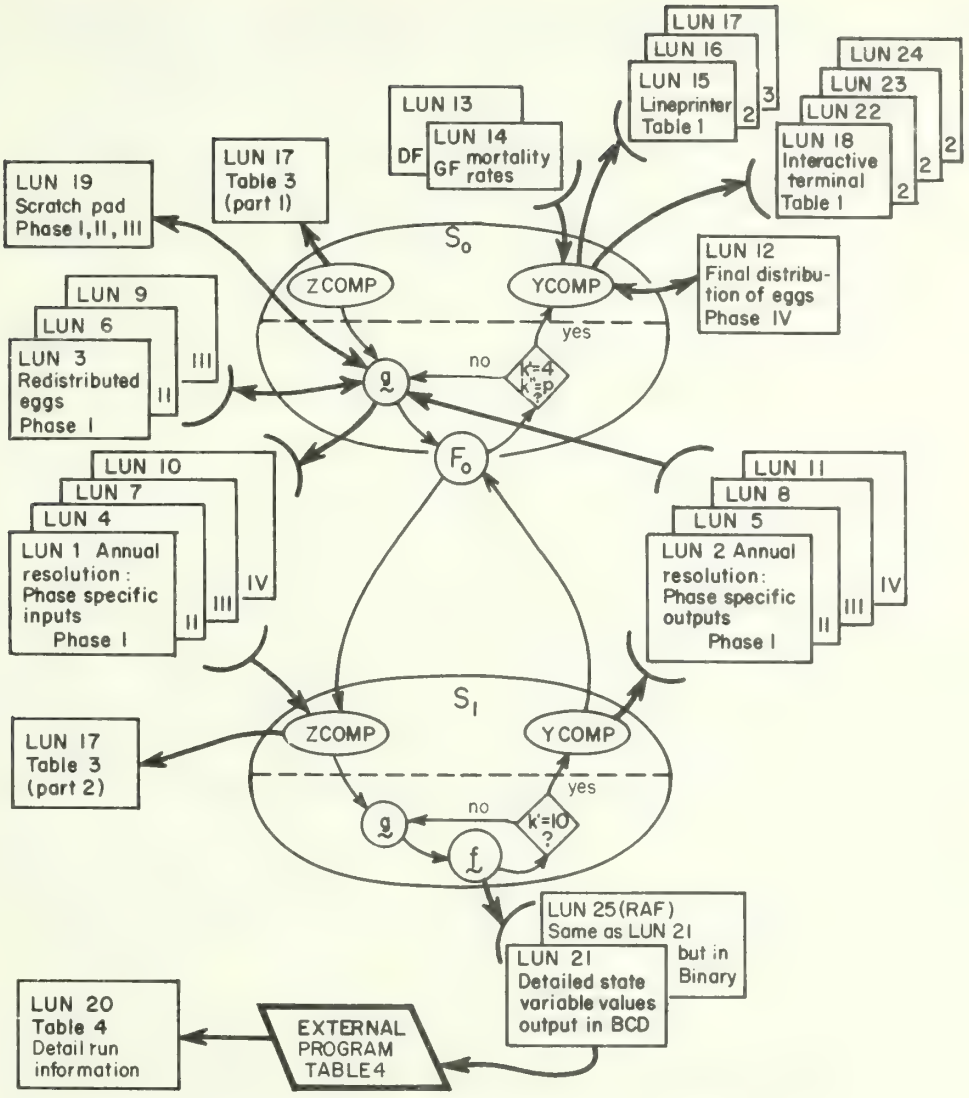


Figure 4.--Stand-outbreak model, Version 3.1: LUN assignment and identity.

LUNs 1, 4, 7, and 10 contain phase-specific initial condition information for phases I, II, III, and IV, respectively. The variable identity, by record on the LUN, is:

$$z_{6j},\ z_{4j},\ z_{5j},\ z_{2j},\ z_{3j},\ x_{5j},\ x_{6j},\ x_{7j},\ j$$

where j is the tree-class identification index, and all variables are those of module S_0.

LUNs 2, 5, 8, and 11 contain phase-specific output conditions from phases I, II, III, and IV, respectively. The variable identity is:

$$y_1,\ y_2,\ y_3$$

where all variables are those of module S_1.

LUNs 3, 6, 9, and 12 contain outputs from the insect redistribution process. The variable identity is:

$$g_{2j}$$

from module S_0.

LUN 19 is used as a "scratch" pad and stores the values $\hat{g}_{3.}$ of module S_0 for each phase, with each successive phase-specific output vector written over the previous vector.

Information is read from and/or written on the LUNs in the following order as a simulation run proceeds (see fig. 3):

(1) Module S_0:

Z Functions: ZCOMP[17] calls special function TABLE31.

Subroutine TABLE31

This subroutine writes most of *table* 3[18] on LUN 17. The parameters that are local to the lower module S_1 are written from that module.

G Functions: LUN 1 has been constructed before the simulation and contains the initial conditions for phase I. Only g_1 returns a value at this time, the other g functions produce no (zero) outputs at k' = 0.

(2) Module S_0 (phase I):

Z Functions: ZCOMP, on the initial entry only, makes a call to the special function TABLE32.

Subroutine TABLE32

This subroutine writes the portion of *table* 3 that contains the destruction/consumption ratios and the larval growth rates on LUN 17.

F Functions: Function $f_{4,4}$ makes a call to special function S_2.

Subroutine S2(b)

This subroutine writes the value of each state variable for each occasion (k') on a random access file, LUN 25, in binary and a duplicate output on LUN 21 in BCD. The material on LUN 25 is then available for access by an external program TABLE4 that will produce detailed information on any state variable at any occasion for each tree class during a simulation; this is produced as output *table* 4 on LUN 20.

---

[17] Two special-purpose standard FLEX subroutines, ZCOMP and YCOMP, are associated with each module in a model. ZCOMP is processed first and YCOMP last in each time step. ZCOMP handles all input-variable processing, and YCOMP handles all output-variable processing.

[18] To distinguish computer output tables from the tables in this paper, the computer output tables will be written in italics, *table*. Subroutines are given in all cap., e.g., TABLE32.

Y Functions: YCOMP[19/] writes the values of y_1, y_2, and y_3 on LUN 2. These are the year-end values of the variables, that is the phase-specific population-branch model outputs.

Module S_1 is processed once for each tree class with no calculation of any g function values in module S_0 during this processing.

(3) Module S_0:

G Functions: Function g_2, through special function REDIST, writes the values $\hat{g}_{2.}$ on LUN 3.

Function g_3 writes the values $\hat{g}_{3.}$ on LUN 19.

Function g_4, utilizing the information on LUNs 1, 2, 3, and 19, writes new values on LUN 4, where x_5 is replaced by the tree class specific values of y_1 from LUN 2, x_6 is replaced by $\hat{g}_{3.}$ from LUN 19 and x_7 is replaced by the values $\hat{g}_{4.}$ produced by this function. LUN 4 now contains the initial conditions for phase II. The replacement done by this function constitutues the updating of variables x_5, x_6, and x_7; this is normally an automatic part of the FLEX algorithm, but because of the vector manipulations occurring in this module, the updating must be done by a user-defined function (see Vector Processing in FLEX2).

All other values are simply transferred unchanged from LUN 1 to LUN 4.

(4) Module S_1 (phase II):

F Functions: Function $f_{4,4}$ makes a call to special function S2.

Y Functions: YCOMP writes the values of y_1, y_2, and y_3 on LUN 5.

Module S_1 is processed once for each tree class with no calculation of g function values in S_0.

(5) Module S_0:

G Functions: Function g_2 writes the values $\hat{g}_{2.}$ on LUN 6.

Function g_3 writes the values $\hat{g}_{3.}$ on LUN 19.

Parallel to what is done in (3) above, function g_4 writes the values $\hat{g}_{4.}$ on LUN 7, as well as transferring other appropriate information from LUNs 4, 5, 6, and 19 to LUN 7. LUN 7 contains phase-III initial conditions.

[19/] Refer to footnote 17 on previous page.

(6) Module S_1 (phase III):

F Functions: Function $f_{4,4}$ makes a call to special function S2.

Y Functions: YCOMP writes the values of y_1, y_2, and y_3 on LUN 8.

Module S_1 is processed once for each tree class with no calculation of g function values in S_0.

(7) Module S_0:

G Functions: Function g_2 writes the values $\hat{g}_{2.}$ on LUN 9.

Function g_3 writes the values $\hat{g}_{3.}$ on LUN 19.

Function g_4 writes the values $\hat{g}_{4.}$ on LUN 10, as well as transferring other appropriate information from LUNs 7, 8, 9, and 19 to LUN 10. LUN 10 contains phase-IV initial conditions.

(8) Module S_1 (phase IV):

F Functions: Function $f_{4,4}$ makes a call to special function S2.

Y Functions: YCOMP writes the values of y_1, y_2, and y_3 on LUN 11.

Module S_1 is processed once for each tree class with no calculation of g function values in S_0.

(9) Module S_0:

Y Functions: YCOMP calls REDIST for computation of the mean fall egg density over the stand after phase IV. REDIST then computes the redistributed egg density for each tree class and writes them as x_7 on LUN 12.

YCOMP then calls the special function subroutines TABLE33 and TABLE12 to complete *table* 3 and produce the output tables 1 and 2.

Subroutine TABLE33

This subroutine completes *table* 3 on LUN 17 by writing the fall mean egg density per model branch over the stand for each phase.

Subroutine TABLE12

This subroutine produces the annual input-output summary of the model branch for each phase and tree class as *table* 1 on LUN 15. It also determines the postoutbreak probabilities of primary and secondary mortality, probabilities of degrees of top-kill, height- and diameter-growth reduction factors for each tree class, all according to the classification structure provided by Boyd Wickman (1963, 1978a, 1978b).

The mortality and top-kill parameters associated with this classification structure are stored on and input to this subroutine from LUNs 13 and 14. This information is used in producing outbreak impacts as *table* 2 on LUN 16.

Additionally, *table* 1 is output on LUN 18 in a format suitable for viewing from an interactive terminal screen. This is done for *table* 2 as well, but with the requirement of outputting it in three parts on LUNs 22, 23, and 24.

STAND-POSTOUTBREAK MODEL

The stand-postoutbreak model is the filter that takes the defoliation history from an outbreak simulation and associates with defoliation for each tree class the expectations of: direct and secondary mortality; degrees of top-kill; and radial- and height-growth impacts.

The development of the mortality and top-kill expectations are based on the history of host tree plots associated with the DFTM outbreak of 1972-1974 in eastern Oregon (Wickman 1978b). The model branch defoliation is translated into crown defoliation via the branch-tree relationship.

For each tree class, branch defoliation is converted into crown defoliation using the logistic equation

$$y = \frac{p_1}{p_2 + p_3 e^{p_1 x}}$$

where for $x,y \varepsilon [0.1]$:

x: model branch defoliation as a proportion of nominal.

y: proportion of crown totally defoliated.

$p_1 = -22.579678$

$p_2 = -22.996253$

$p_3 = -598,181,961.$

These parameters were obtained by nonlinear least squares curve fit to means of data from the six crown-defoliation classes of Wickman (1978b). Crown defoliation determines one of seven possible effects vectors. The vector is used to partition the trees of the tree class into direct and secondary mortality or a range of top-kill and growth loss. The set of vectors that determine these losses is derived from the input files read from LUNs 13 and 14 given in appendix C. The same algorithm is used

for each host-specific file. The information on these files is structured as follows: the first seven contain direct mortality and top-kill information; the remaining two contain secondary mortality information. Letting A(i,j) be the jth entry from the ith row, one has the following correspondences: For i =

1: all parameters correspond to trees (a tree class) with less than 15% of the crown totally defoliated,

2: all parameters correspond to trees with between 15% and 35% of the crown totally defoliated,

3: parameters for trees with between 35% and 65% of the crown totally defoliated,

4: parameters for trees with between 65% and 85% of the crown totally defoliated,

5: parameters for trees with between 85% and 95% of the crown totally defoliated,

6: parameters for trees with between 95% and 99.5% of the crown totally defoliated,

7: parameters for trees with greater than 99.5% of the crown totally defoliated,

and for each of the above values of i, the following definitions are given of A(i,j) for j =

1: expected proportion of trees for which mortality is directly attributable to defoliation,

2: expected proportion of trees with no top-kill damage,

3: expected proportion of trees with leader-kill, 1 year's growth only,

4: expected proportion of trees with top-kill less than 10%,

5: expected proportion of trees with top-kill less than 25%,

6: expected proportion of trees with top-kill less than 50%,

7: expected proportion of trees with some top-kill,

8: expected loss in diameter growth from defoliation.

The last two records in these files contain the information necessary to remove secondary mortality from the arrays described above. They are as follows: A(i,j) for i=

8: expectations of secondary mortality associated with bark beetle attack,

9: expectations of secondary mortality from all other causes, e.g., windthrow, winterkill, natural attrition,

and for j =

1: expectation for trees without top-kill,

2: expectation for trees with leader-kill only,

3: expectation for trees with more than leader-kill, but less than 10% top-kill,

4: expectation for trees with top-kill between 10% and 25%,

5: expectation for trees with top-kill between 25% and 50%,

6: expectation for trees with top-kill greater than 50%.

Because the top-kill information on the external files is cumulative, differences are taken between successive classes to get the number for each interval. From the resulting classes, secondary mortality is removed after combining the two secondary mortality factors--that caused by bark beetles and that caused by other factors such as windtnrow, snow, fire, and other "unknown" causes.

The two forms of secondary mortality are assumed to act independently, hence the two vectors are combined by the rule:

$$(m_{1,j} + m_{2,j} - m_{1,j}m_{2,j}) = v_j.$$

The scalar- or dot-product of this vector with the input vector of residuals of direct mortality is then used to compute secondary mortality for each defoliation class:

$$\sum_{j=2}^{6} v_j r_{i,j+1} = s_i, \quad i=1, \ldots, 7.$$

Here $r_{i,j}$ is the vector of residuals (ith record of LUN 13 or LUN 14), and s_i is the derived secondary mortality that will be used in *table* 2 of simulation output (appendix C).

After secondary mortality has been subtracted from the residuals of direct mortality, the remaining numbers are the expected proportions that are to receive various levels of top-kill, and one class that indicates the proportion receiving only growth reductions.

Growth reductions attributable to defoliation are changes in diameter growth at breast height and height growth. Growth reduction is a function of maximum model branch defoliation. These assumptions result in the following table of possible effect vectors. One vector is chosen by species and defoliation.

An example of defoliation impact summaries is given in *table* 2 of the output section of appendix C.

Output expectations of mortality and top-kill by tree defoliation

Douglas-fir host:

Percent of crown totally defoliated	Direct mortality	Secondary mortality	Top-kill (total)	Growth impacts only	Expected top-kill: Leader kill	1-10% of crown	10-25% of crown	25-50% of crown	50-90% of crown
0-15	0	.1127	.1129	.7744	.0675	.0454	0	0	0
16-35	0	.1229	.2081	.6690	.1360	.0696	0	0	.0026
36-65	.0090	.0927	.4032	.4951	.1744	.2058	0	.0230	0
66-85	.0280	.1000	.4820	.3900	.2376	.1606	0	.0838	0
86-95	.1730	.1950	.2929	.3391	.1400	.0607	0	.0782	.0140
96-99.5	.4770	.1070	.1864	.2296	.1422	.0359	0	0	.0083
99.5-100	.9230	.0158	.0274	.0338	.0209	.0053	0	0	.0012

Grand fir host:

Percent of crown totally defoliated	Direct mortality	Secondary mortality	Top-kill (total)	Growth impacts only	Expected top-kill: Leader kill	1-10% of crown	10-25% of crown	25-50% of crown	50-90% of crown
0-15	0	.0451	.0544	.9005	.0331	.0123	.0039	.0029	.0022
16-35	0	.0422	.1261	.8316	.0877	.0294	.0068	.0019	.0004
36-65	.0090	.0455	.2674	.6781	.1322	.0882	.0317	.0113	.0039
66-85	.0280	.0592	.3817	.5311	.1723	.1022	.0424	.0480	.0168
86-95	.1730	.0957	.3387	.3926	.1893	.0580	.0217	.0157	.0541
96-99.5	.4770	.0790	.2137	.2302	.0963	.0401	.0274	0	.0499
99.5-100	.9230	.0116	.0315	.0339	.0142	.0059	.0040	0	.0074

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LITERATURE CITED

White, Curtis, and W. S. Overton.
1977. Users manual for the FLEX2 and FLEX3 model processors for the FLEX modelling paradigm. Forest Research Laboratory, School of Forestry, Oregon State University, Corvallis, Oregon. 138 p.

Wickman, Boyd E., Richard R. Mason, and C. G. Thompson.
1973. Major outbreaks of the Douglas-fir tussock moth in Oregon and California. USDA For. Serv. Gen. Tech. Rep. PNW-5, 18 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Wickman, Boyd E.
1963. Mortality and growth reduction of white fir following defoliation by the Douglas-fir tussock moth. USDA For. Serv. Res. Paper, PSW-7, 15 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Wickman, Boyd E.
1978a. A case study of a Douglas-fir tussock moth outbreak and stand conditions 10 years later. USDA For. Serv. Res. Paper PNW-244, 22 p. Pac. Northwest For. Range Exp. Stn., Portland, Oreg.

Wickman, Boyd E.
1978b. Tree mortality and top-kill related to defoliation by the Douglas-fir tussock moth in the Blue Mountains outbreak. USDA For. Serv. Res. Paper PNW-233, 47 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

APPENDIX A VERSION 3.1 SOURCE CODE

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```
EOD ON INPUT UNIT
00001 -MODULEGET()=1
00002 -NUMBER=7 O=4 MODULETYPE=1 P=24
00003 -TMAX=1 FUNLOAD=*V31S0
00004 -YMAX=3 NODUMP NOLOG TTYOFF NOSUMMARY
00005 -TITLE= S(1) REVISED  STAND OUTBREAK  MODULE
00006 -B()=0.,  0.,  0.,  0.,  0.,  0.,  0.,  0.,  0.,  0.,
00007 -  0.001,0.001,0.002,0.003,0.006,0.013,0.035,0.028,0.025,0.029,
00008 -0.031,0.034,0.035,0.035,0.0,0.0,0.0,0.0,0.0,0.0,
00009 -0.,0.,0.,0.,0.001,0.001,0.001,0.002,0.003,0.010,
00010 -0.016,0.042,0.065,0.096,0.097,0.021,0.033,0.056,0.5,0.62,
00011 -0.75,0.80,200.,200.,150.,150.,0.,0.50,0.60,0.85,
00012 -0.90,0.
00013 -R()= 1.0, 0.75, 0.1,  0.,  0.,  0.,  1.0,  0.8,  0.5,  0.1,
00014 -  0.,  0.,  0.02,  0.02,  0.02,  0.02,  0.02,  0.02,  0.02,  0.02
00015 -MODULEGET()=1,1
00016 -NUMBER=4 O=10 TARGET
00017 -TMAX=1 FUNLOAD=*V31S1
00018 -DUMPLUN=40
00019 -O=Y(1) O=Y(2) O=Y(3)
00020 -YMAX=3
00021 -LP=Y(1) LP=Y(2) LP=Y(3)
00022 -O=Y(1) O=Y(2) O=Y(3)
00023 -B()=.02,  .02,  .02,  .02,  .02,  .02,  5.4,  6.25, 6.25, 2.71,
00024 -  2.27, 2.0,  5.4,  6.25, 6.25, 3.69, 3.29, 3.0,  1.19, .381,
00025 -  0.10, .1147, .1886, .0625, .197, 52.0626838, .02,0.01,0.5,0.50
00026 -TITLE=SIMULATION ON THE REVISED MODEL VERS. 3.
00027 -TTYOFF NOSUMMARY
00028 -MODULEGET()=1
00029 -FIRSTSUB()=1,1
00030 -MODULEGET()=1,1
00031 -GHOST()=1
00032 -INPUT=60
EOF ON INPUT UNIT
```

```
00001 -C
00002 -C   *** S(0) MODULE V3.1 DFTM MODEL ***
00003 -C
00004 -       SUBROUTINE ZCOMP (K,X,B,R,Z,T0,T,G)
00005 -       DIMENSION X(1),B(1),R(1),Z(1),G(1)
00006 -       WRITE(61,2000)
00007 - 2000 FORMAT(' ENTER NUMBER OF TREE CLASSES IN STAND')
00008 -       Z(1)=FFIN(60)
00009 -       B(57)=Z(1)
00010 -C
00011 -C *** WRITE THE BEGINNING OF TABLE 3 ***
00012 -C
00013 -       CALL TABLE31(B,R)
00014 -       RETURN
00015 -       END
00016 -C
00017 -C
00018 -C
00019 -C
00020 -C
00021 -       FUNCTION G01(K,X,B,R,Z,KP)
00022 -       DIMENSION X(1),B(1),R(1),Z(1)
00023 -       G01=FLOAT(KP+1)
00024 -       RETURN
00025 -       END
00026 -C
00027 -C
00028 -       FUNCTION G02 (K,X,B,R,Z,KP)
00029 -       DIMENSION X(1),B(1),R(1),Z(1)
00030 -       G02=0.
00031 -       IF (KP.EQ.IPHASE) RETURN
00032 -       IF (KP.EQ.0) RETURN
00033 -       INUM=IFIX(B(57))
00034 -       CALL REDIST(KP,INUM,B,X)
00035 -       IPHASE=KP
00036 -       RETURN
00037 -       END
00038 -C
00039 -C
00040 -       FUNCTION G03(K,X,B,R,Z,KP)
00041 -       DIMENSION X(1),B(1),R(1),Z(1)
00042 -       G03=0.
00043 -       IP=KP+1
00044 -       IF (IP.EQ.IPHASE) RETURN
00045 -       IF(KP.EQ.0) RETURN
00046 -       NN=IFIX(Z(1))
00047 -       LUN=(IP-2)*2
00048 -       LUN1=LUN+1
00049 -       LUN2=LUN+2
00050 -       LUN19=19
00051 -       REWIND LUN1
00052 -       REWIND LUN2
00053 -       REWIND LUN19
00054 -       DO 10 J=1,NN
00055 -       READ(LUN1,1000) Z2,Z3
00056 - 1000 FORMAT(24X,2F11.5)
00057 -       READ(LUN2,1001) X6
00058 - 1001 FORMAT(12X,1F12.6)
00059 -       G3=FMIN((1.-Z2/100)*Z3,X6)
00060 -       WRITE(LUN19,1002) G3
00061 - 1002 FORMAT(1F12.6)
00062 - 10    CONTINUE
00063 -       IPHASE=IP
00064 -       RETURN
00065 -       END
00066 -C
00067 -C
00068 -       FUNCTION G04(K,X,B,R,Z,KP)
00069 -       DIMENSION X(1),B(1),R(1),Z(1)
00070 -       G04=0.
00071 -       IP=KP+1
00072 -       IF (IP.EQ.IPHASE) RETURN
00073 -       IF (KP.EQ.0) RETURN
00074 -       NN=IFIX(Z(1))
00075 -       LUN=(IP-2)*3
00076 -       LUN1=LUN+1
00077 -       LUN2=LUN+2
00078 -       LUN3=LUN+3
00079 -       LUN4=LUN+4
00080 -       LUN19=19
```

```
00081 -       REWIND LUN1
00082 -       REWIND LUN2
00083 -       REWIND LUN3
00084 -       REWIND LUN4
00085 -       REWIND LUN19
00086 -       DO 120 I=1,NN
00087 -       READ (LUN1,2000) IZ6,Z4,Z5,Z2,Z3,J
00088 - 2000  FORMAT (1I2,4F11.5,33X,1I3)
00089 -       READ (LUN2,2200) X5
00090 -       READ (LUN3,2200) G2
00091 -       READ (LUN19,2200) G3
00092 - 2200  FORMAT (1F12.6)
00093 -       IPP=IP+56
00094 -       X7=(1.-R(IPP))*G2
00095 -       X6=G3
00096 - 120   WRITE(LUN4,2300) IZ6,Z4,Z5,Z2,Z3,X5,X6,X7,J
00097 - 2300  FORMAT (1I2,7F11.5,1I3)
00098 -       REWIND LUN4
00099 -       IPHASE=IP
00100 -       RETURN
00101 -       END
00102 -C
00103 -C
00104 -       SUBROUTINE YCOMP(K,X,B,R,Y,XS,T)
00105 -       DIMENSION X(1),B(1),R(1),Y(1),XS(1)
00106 -       KP=4
00107 -       IB57=IFIX(B(57))
00108 -       CALL REDIST(KP,IB57,B,X)
00109 -C
00110 -C  ***      FINISH TABLE 3, ON LUN 17       ***
00111 -C
00112 -       CALL TABLE33(X,B)
00113 -C
00114 -C  ***      WRITE TABLES 1 AND 2      ***
00115 -C
00116 -       CALL TABLE12(P)
00117 -       RETURN
00118 -       END
00119 -C
00120 -C
00121 -       SUBROUTINE REDIST(KP,INUM,B,X)
00122 -       DIMENSION B(1),X(1),XYCOMP(4)
00123 -C
00124 -C            INITIALIZE LUN VALUES AND REWIND
00125 -C
00126 -       LUN1=(KP-1)*3+1
00127 -       LUN2=(KP-1)*3+2
00128 -       LUN3=(KP-1)*3+3
00129 -       REWIND LUN1
00130 -       REWIND LUN2
00131 -C
00132 -C  ***                 REDISTRIBUTION OF EGGS          ***
00133 -C            INITIALIZE LOCAL VARIABLES
00134 -C
00135 -       SUM=TOTSTEM=0.0
00136 -C
00137 -C            CALCULATE TOTAL EGGS OVER STAND (SUM)
00138 -C            AND TOTAL WEIGHTED SUM OF TREES(TOTSTEM)
00139 -C
00140 -       DO 10 J=1,INUM
00141 -       READ(LUN1,1001) Z4,Z5
00142 - 1001  FORMAT(2X,2F11.5)
00143 -       READ (LUN2,1000) X7
00144 - 1000  FORMAT (24X,F12.6)
00145 -       SUM=SUM+X7*Z4*Z5
00146 -       TOTSTEM=TOTSTEM+Z4*Z5
00147 - 10    CONTINUE
00148 -C
00149 -C            CALCULATE X(KP) WHERE KP IS PREVIOUS PHASE
00150 -C            STORE LOCALLY IN XYCOMP(KP) UNTIL PHASE IV
00151 -C            TO PREVENT XS=0 FROM ERASING STORED VALUES
00152 -C
00153 -       XYCOMP(KP)=SUM/TOTSTEM
00154 -       REWIND LUN2
00155 -C
00156 -C            CALCULATE VALUES OF G(2,J) FOR SO HERE,
00157 -C            INSTEAD OF IN FUNCTION G02 CODE AND WRITE ON LUN 3
00158 -C
00159 -       DO 20 J=1,INUM
```

```
00160 -       READ (LUN2,1000) X7
00161 -       G2=X7+S2(G2)*(XYCOMP(KP)-X7)
00162 -       WRITE (LUN3,1010) G2
00163 - 1010  FORMAT(F12.6)
00164 - 20    CONTINUE
00165 -       IF(KP.EQ.4) GO TO 25
00166 -       RETURN
00167 -C
00168 -C            TRANSFER VALUES FROM LOCAL STORAGE TO X ARRAY
00169 -C
00170 -    25 DO 30 I=1,4
00171 -       X(I)=XYCOMP(I)
00172 - 30    CONTINUE
00173 -       RETURN
00174 -       END
EOF ON INPUT UNIT
```

```
00001 -C
00002 -C            FLEX FUNCTIONS FOR V3.1 DFTM MODULE S(1)
00003 -C
00004 -C
00005 -       SUBROUTINE ZCOMP (K,X,B,R,Z,T0,T,G)
00006 -       DIMENSION X(1),B(1),R(1),Z(1),G(1)
00007 -C
00008 -C***     READ IN THE Z VECTOR, INITIAL X VECTOR    ***
00009 -C
00010 -       CALL VARIN (Z(3),G(1))
00011 -       IP=IFIX (Z(3))
00012 -       LUN1=(IP-1)*3+1
00013 -       READ (LUN1,1000) ISPECIES,Z(1),Z(2),X(1),X(2),X(3)
00014 - 1000 FORMAT (1I2,22X,5F11.5)
00015 -       Z(4)=FLOAT(ISPECIES)
00016 -       X(4)=0.0
00017 -C
00018 -C *** SET PHASE-SPECIFIC PARAMETERS B(29) AND B(34--36)
00019 -C
00020 -       B(29)=Z(3)
00021 -       CALL VARIN(B(34),B(IP+48))
00022 -       CALL VARIN (B(35),B(IP+52))
00023 -       CALL VARIN (B(36),B(IP+62))
00024 -C
00025 -C***      READ IN HOST AND PHASE SPECIFIC MORTALITY VECTORS    ***
00026 -C
00027 -       DO 6 J=1,6
00028 -       I1=J+(IP-1)*6
00029 -       I2=J+(IP+3)*6
00030 -       I3=J+(ISPECIES-1)*6
00031 -       CALL VARIN (R(J),R(J+12))
00032 -       CALL VARIN (R(J),R(I1))
00033 -       CALL VARIN (R(J+6),R(I2))
00034 -     6 CALL VARIN (R(J+12),R(I3))
00035 -       IF (K.NE.0) RETURN
00036 -C
00037 -C *** FINISH TABLE 3 ON LUN 17 ***
00038 -C
00039 -       CALL TABLE32(B)
00040 -       RETURN
00041 -       END
00042 -C
00043 -C
00044 -C
00045 -C
00046 -C
00047 -       FUNCTION G01 (K,X,B,R,Z,KP)
00048 -       DIMENSION X(1),B(1),R(1),Z(1)
00049 -       G01=0.
00050 -       IF(KP.EQ.8) G01=(Z(2)*Z(1)/100.)*((X(1)+X(2)+Z(2))/
00051 -      A   (2.0*Z(2))-G(19)*B(27))
00052 -       RETURN
00053 -       END
00054 -C
00055 -C
00056 -       FUNCTION G03 (K,X,B,R,Z,KP)
00057 -       DIMENSION X(1),B(1),R(1),Z(1)
00058 -       G03=0.0
00059 -       IF (KP.EQ.8) G03=X(1)
00060 -       RETURN
00061 -       END
00062 -C
00063 -C
00064 -       FUNCTION G04 (K,X,B,R,Z,KP)
00065 -       DIMENSION X(1),B(1),R(1),Z(1)
00066 -       G04=0.0
00067 -       IF (KP.GT.0.AND.KP.LE.6)G04=FMIN(G(16),X(1))
00068 -       RETURN
00069 -       END
00070 -C
00071 -C
00072 -       FUNCTION G05 (K,X,B,R,Z,KP)
00073 -       DIMENSION X(1),B(1),R(1),Z(1)
00074 -       G05=0.0
00075 -       IF (KP.GE.1.AND.KP.LE.6) G05=FMIN(G(18),X(2))
00076 -       RETURN
00077 -       END
00078 -C
00079 -C
```

```
00080 -       FUNCTION G06 (K,X,B,R,Z,KP)
00081 -       DIMENSION X(1),B(1),R(1),Z(1)
00082 -       G06=0.
00083 -       IF(KP.GT.0.AND.KP.LE.6) G06=(1.-R(KP))*(1.-R(KP+6))*(1.-R(KP))
00084 -       RETURN
00085 -       END
00086 -C
00087 -C
00088 -       FUNCTION G07 (K,X,B,R,Z,KP)
00089 -       DIMENSION X(1),B(1),R(1),Z(1)
00090 -       G07=0.
00091 -       IF(KP.GT.0.AND.KP.LE.6) G07=1.-R(KP+12)
00092 -       RETURN
00093 -       END
00094 -C
00095 -C
00096 -       FUNCTION G08 (K,X,B,R,Z,KP)
00097 -       DIMENSION X(1),B(1),R(1),Z(1)
00098 -       G08=0.
00099 -       IF (KP.EQ.0.OR.KP.GT.6) RETURN
00100 -       G08=G(6)**10.-1.
00101 -       IF(G(15).NE.10..AND.G(7).NE.0.)G08=(G(6)**10.)*(G(7)**(10.
00102 -      C-G(15)))-1.
00103 -       IF (G(7).EQ.0..AND.G(15).NE.10.) G08=-1.
00104 -       RETURN
00105 -       END
00106 -C
00107 -C
00108 -       FUNCTION G09 (K,X,B,R,Z,KP)
00109 -       DIMENSION X(1),B(1),R(1),Z(1)
00110 -       IF(KP.EQ.0.OR.KP.EQ.3) GTOT=0.
00111 -       GTOT=GTOT+G(17)
00112 -       G09=GTOT
00113 -       RETURN
00114 -       END
00115 -C
00116 -C
00117 -       FUNCTION G10 (K,X,B,R,Z,KP)
00118 -       DIMENSION X(1),B(1),R(1),Z(1)
00119 -       G10=0.
00120 -       IF(KP.EQ.0)G10=-R(36)
00121 -       IF(KP.EQ.5) G10=-(1.+G(8))*B(30)
00122 -       IF(KP.EQ.7) G10=-B(34)
00123 -       IF(KP.EQ.8) G10=(R(35)*G(14)*(1.0-R(28)*G(9))-1.0)
00124 -       RETURN
00125 -       END
00126 -C
00127 -C
00128 -       FUNCTION G11 (K,X,B,R,Z,KP)
00129 -       DIMENSION X(1),B(1),R(1),Z(1)
00130 -       G11=(G(8)+G(10))*X(3)
00131 -       RETURN
00132 -       END
00133 -C
00134 -C
00135 -
00136 -       FUNCTION G12 (K,X,B,R,Z,KP)
00137 -       DIMENSION X(1),B(1),R(1),Z(1)
00138 -       G12=0.
00139 -       IF(X(3).LE.0..OR.X(1)+X(2).LE.0.) GO TO 10
00140 -       IF(KP.GE.1.AND.KP.LT.4) G12=B(22)
00141 -       IF(KP.EQ.4) G12=B(23)
00142 -       IF(KP.GT.4.AND.KP.LE.6) G12=B(24)
00143 -   10  RETURN
00144 -       END
00145 -C
00146 -C
00147 -       FUNCTION G13 (K,X,B,R,Z,KP)
00148 -       DIMENSION X(1),B(1),R(1),Z(1)
00149 -       G13=0.
00150 -       IF(KP.EQ.0) G13=B(25)
00151 -       PHI=(G(4)+G(5))/(G(4)+G(18))
00152 -       IF(KP.GT.0.AND.KP.LE.6) G13=X(4)*(EXP(10.*G(12)*PHI)-1.)
00153 -       RETURN
00154 -       END
00155 -C
00156 -C
00157 -       FUNCTION G14 (K,X,B,R,Z,KP)
00158 -       DIMENSION X(1),B(1),R(1),Z(1)
00159 -       G14=FMAX(2.*X(4)/B(26)-1.,0.)
00160 -       RETURN
00161 -       END
```

```
00162 -C
00163 -C
00164 -       FUNCTION G15 (K,X,B,R,Z,KP)
00165 -       DIMENSION X(1),B(1),R(1),Z(1)
00166 -       IF(KP.EQ.0.OR.KP.GT.6) GO TO 15
00167 -       DO 10 I=0,10
00168 -       ALPHA=FLOAT(10-I)
00169 -       G15=ALPHA
00170 -       IF(UV1(KP,X,B,ALPHA).LT.X(1)) RETURN
00171 - 10    CONTINUE
00172 -       RETURN
00173 - 15    G15=0.
00174 -       RETURN
00175 -       END
00176 -C
00177 -C
00178 -       FUNCTION G16 (K,X,B,R,Z,KP)
00179 -       DIMENSION X(1),B(1),R(1),Z(1)
00180 -       G16=0.
00181 -       IF(KP.EQ.0.OR.KP.GT.6)RETURN
00182 -       ALPHA=FMIN(G(15)+1.,10.)
00183 -       IF(X(1).GT.0.0)G16=UV1(KP,X,B,ALPHA)
00184 -       RETURN
00185 -       END
00186 -C
00187 -C
00188 -       FUNCTION G17 (K,X,B,R,Z,KP)
00189 -       DIMENSION X(1),B(1),R(1),Z(1)
00190 -       IF(KP.EQ.0.OR.KP.GT.6) GO TO 20
00191 -       G17=10.-G(15)
00192 -       ALPHA=G(15)
00193 -       N=IFIX(10.-G(15))
00194 -       DO 10 I=0,N
00195 -       ETA=FLOAT(I)
00196 -       ETAPLUS=ETA+1.
00197 -       IF((UV2(KP,X,B,ALPHA,ETAPLUS)-(X(1)-UV1(KP,X,B,ALPHA)))
00198 -      C.GT.X(2)) GO TO 15
00199 - 10    CONTINUE
00200 -       RETURN
00201 - 15    G17=ETA
00202 -       RETURN
00203 - 20    G17=0.
00204 -       RETURN
00205 -       END
00206 -C
00207 -C
00208 -       FUNCTION G18 (K,X,B,R,Z,KP)
00209 -       DIMENSION X(1),B(1),R(1),Z(1)
00210 -       G18=0.
00211 -       IF (KP.EQ.0.OR.KP.GT.6) RETURN
00212 -       ALPHA=G(15)
00213 -       ETA=10.-ALPHA
00214 -       G18=UV2(KP,X,B,ALPHA,ETA)-(X(1)-UV1(KP,X,B,ALPHA))
00215 -       IF (G18.LT.0.) G18=0.
00216 -       RETURN
00217 -       END
00218 -C
00219 -C
00220 -       FUNCTION G19 (K,X,B,R,Z,KP)
00221 -       DIMENSION X(1),B(1),R(1),Z(1)
00222 -       IF(KP.EQ.0.OR.KP.EQ.9) GTOT=0.
00223 -       IF(KP.GT.0.AND.KP.LE.6)GTOT=GTOT+(10.-(G(15)+G(17)))
00224 -       G19=GTOT
00225 -       RETURN
00226 -       END
00227 -C
00228 -C
00229 -       FUNCTION F0101(K,X,B,R,Z,KP)
00230 -       DIMENSION X(1),B(1),R(1),Z(1)
00231 -       F0101=10.0*(G(1)-G(4))
00232 -       RETURN
00233 -       END
00234 -C
00235 -C
00236 -       FUNCTION F0102(K,X,B,R,Z,KP)
00237 -       DIMENSION X(1),B(1),R(1),Z(1)
00238 -       F0102=10.0*G(3)
00239 -       RETURN
00240 -       END
00241 -C
00242 -C
```

```
00243 -       FUNCTION F0202(K,X,B,R,Z,KP)
00244 -       DIMENSION X(1),B(1),R(1),Z(1)
00245 -       F0202=10.0*(-G(5))
00246 -       RETURN
00247 -       END
00248 -C
00249 -C
00250 -       FUNCTION F0303(K,X,B,R,Z,KP)
00251 -       DIMENSION X(1),B(1),R(1),Z(1)
00252 -       F0303=10.0*G(11)
00253 -       RETURN
00254 -       END
00255 -C
00256 -C
00257 -       FUNCTION F0404 (K,X,B,R,Z,KP)
00258 -       DIMENSION X(1),B(1),R(1),Z(1)
00259 -       F0404=G(13)*10.0
00260 -       CALL S2(X,KP,F0404)
00261 -       RETURN
00262 -       END
00263 -C
00264 -C
00265 -C
00266 -C
00267 -C
00268 -       SUBROUTINE YCOMP (K,X,B,R,Y,XS,T)
00269 -       DIMENSION X(1),B(1),R(1),Y(1)
00270 -       DO 10 I=1,3
00271 -    10 Y(I)=X(I)
00272 -       IF (K.EQ.0) RETURN
00273 -       IP=IFIX(B(29))
00274 -       LUN2=(IP-1)*3+2
00275 -       WRITE (LUN2,1000) Y(1),Y(2),Y(3)
00276 - 1000 FORMAT (3F12.6)
00277 -       RETURN
00278 -       END
00279 -C
00280 -C
00281 -       FUNCTION UV1 (KP,X,B,ALPHA)
00282 -       DIMENSION X(1),B(1)
00283 -       UV1=0.
00284 -       IF(KP.EQ.0.OR.KP.GT.6) RETURN
00285 -       U=X(3)*X(4)
00286 -       I=KP+6
00287 -       UV1=U*(B(19)+B(20)/G(12))*(EXP(G(12))-1.)*0.001/B(21)*B(I)*
00288 -      C(1.-(G(6)*EXP(G(12)))**ALPHA)/(1.-G(6)*EXP(G(12)))
00289 -       RETURN
00290 -       END
00291 -C
00292 -C
00293 -       FUNCTION UV2 (KP,X,B,ALPHA,ETA)
00294 -       DIMENSION X(1),B(1)
00295 -       UV2=0.
00296 -       IF(KP.EQ.0.OR.KP.GT.6) RETURN
00297 -       U=X(3)*X(4)
00298 -       I=KP+12
00299 -       IF(G(7).EQ.0..AND.ETA.EQ.0.) RETURN
00300 -       UV2=U*(B(19)+B(20)/G(12))*(EXP(G(12))-1.)*0.001/B(21)*B(I)*
00301 -      CG(6)**ALPHA*EXP(ALPHA*G(12))*(1.-(G(6)*G(7)*EXP(G(12)))**ETA)/
00302 -      C(1.-G(6)*G(7)*EXP(G(12)))
00303 -       RETURN
00304 -       END
EOF ON INPUT UNIT
```

```
00001 -       SUBROUTINE TABLE31(B,R)
00002 -       DIMENSION B(1),R(1)
00003 -C
00004 -C            BEGIN TABLE 3 ON LUN 17
00005 -C            OBTAIN TIME AND DATE
00006 -C
00007 -       TIME=0.
00008 -       DATE=0.
00009 -       EM=0.
00010 -       CALL XREQ (330,0,0,EM,TIME)
00011 -       CALL XREQ (328,0,0,EM,DATE)
00012 -C
00013 -C            WRITE HEADING ON LUN 17
00014 -C
00015 -       WRITE (17,1000) TIME,DATE
00016 -C
00017 - 1000 FORMAT(≠1≠,/≠-≠,/≠-≠,9X,≠TABLE 3:  PARAMETERS FOR AN≠
00018 -      C,≠ OUTBREAK:≠,
00019 -      C≠ MORTALITY, FOLIAGE DESTRUCTION, AND OTHER.≠
00020 -      C,14X,2(2X,A8)/≠0≠,19X,
00021 -      C≠HOST TREE, STAND, PHASE, OR INSTAR SPECIFIC.≠/≠-≠,9X,
00022 -      C≠DESCRIPTION≠,9X,≠PHASE≠,5X,≠SPECIES≠,21X,≠INSTAR≠,26X,
00023 -      C≠PUPAE≠,5X,≠OVERWINTER≠,6X,≠EGG MASS≠/≠ ≠,52X,≠1≠,6X,≠2≠,
00024 -      C6X,≠3≠,6X,≠4≠,6X,≠5≠,6X,≠6≠,9X,≠MORTALITY   MORTALITY≠,
00025 -      C 9X,≠SIZE≠/≠ ≠,
00026 -      C135(≠-≠)/≠0   DAILY MORTALITY RATE≠/≠  ≠,24(≠-≠))
00027 -C
00028 -C            WRITE BACKGROUND DAILY MORTALITY RATES
00029 -C
00030 -       WRITE (17,1010) (B(J),J=13,18)
00031 - 1010 FORMAT(≠0≠,9X,≠BACKGROUND≠,8X,≠I,IT,III,IV DF,GF≠,5X,
00032 -      C6(1X,F5.3,1X))
00033 -C
00034 -C            WRITE DAILY DISEASE MORTALITY RATES
00035 -C            PHASES I, II, III, IV
00036 -C
00037 -       WRITE(17,1020) (B(J),J=1,6)
00038 - 1020 FORMAT(≠0≠,9X,≠DISEASE≠,15X,≠I≠,7X,≠DF,GF≠,5X,6(1X,F5.3,1X))
00039 -       WRITE (17,1030) (B(J),J=7,12)
00040 - 1030 FORMAT(≠ ≠,30X,≠II≠,7X,≠DF,GF≠,5X,6(1X,F5.3,1X))
00041 -       WRITE(17,1040) (B(J),J=13,18)
00042 - 1040 FORMAT(≠ ≠,30X,≠III≠,6X,≠DF,GF≠,5X,6(1X,F5.3,1X))
00043 -       WRITE (17,1045) (B(J),J=19,24)
00044 -1045  FORMAT (≠ ≠,30X,≠IV≠,7X,≠DF,GF≠,5X,6(1X,F5.3,1X))
00045 -C
00046 -C            WRITE DAILY PARASITE/PREDATOR MORTALITY RATES
00047 -C            PHASES I, II, III, IV
00048 -C
00049 -       WRITE (17,1050) (B(J),J=25,30)
00050 - 1050 FORMAT(≠0≠,9X,≠PARASITE/PREDATOR≠,5X,≠I≠,7X,≠DF,GF≠,5X,
00051 -     1       6(1X,1F5.3,1X))
00052 -       WRITE(17,1060) (B(J),J=31,36)
00053 - 1060 FORMAT(≠ ≠,30X,≠II≠,7X,≠DF,GF≠,5X,6(1X,F5.3,1X))
00054 -       WRITE (17,1070) (B(J),J=37,42)
00055 - 1070 FORMAT(≠ ≠,30X,≠III≠,6X,≠DF,GF≠,5X,6(1X,F5.3,1X))
00056 -       WRITE (17,1075) (B(J),J=43,48)
00057 -1075  FORMAT (≠ ≠,30X,≠IV≠,7X,≠DF,GF≠,5X,6(1X,1F5.3,1X))
00058 -C
00059 -C            WRITE HOST-SPECIFIC DAILY STRESS MORTALITY RATES
00060 -C            PHASES I, II, III, IV
00061 -C
00062 -       WRITE(17,1080) (B(J),J=1,6)
00063 - 1080 FORMAT(≠0≠,9X,≠STRESS≠,12X,≠I, II,III,IV≠,2X,≠DF≠,7X,6(X,F5.3,X))
00064 -       WRITE (17,1090) (B(J),J=7,12)
00065 - 1090 FORMAT(≠ ≠,27X,≠I,II,III,IV≠,2X,≠GF≠,7X,6(X,F5.3,X))
00066 -C
00067 -C            WRITE SUB-HEADING
00068 -C
00069 -       WRITE  (17,1095)
00070 - 1095 FORMAT(≠  ≠,24(≠-≠)/≠0 OCCASION MORTALITY RATE≠/≠  ≠,24(≠-≠))
00071 -C
00072 -C            WRITE PUPATION MORTALITY RATES
00073 -C            PHASES I, II, III, IV
00074 -C
00075 -       WRITE(17,1100) B(49)
00076 - 1100 FORMAT(≠0≠,10X,≠PUPAE≠,16X,≠I≠,7X,≠DF,GF≠,55X,F5.3)
00077 -       WRITE (17,1110) B(50)
00078 - 1110 FORMAT(≠ ≠,30X,≠II≠,7X,≠DF,GF≠,55X,F5.3)
00079 -       WRITE(17,1120) B(51)
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00080 - 1120 FORMAT(≠ ≠,30X,≠III≠,6X,≠DF,GF≠,55X,F5.3)
00081 -      WRITE (17,1125) B(52)
00082 -1125  FORMAT (≠ ≠,30X,≠IV≠,7X,≠DF,GF≠,55X,1F5.3)
00083 -C
00084 -C           WRITE OVERWINTER EGG MORTALITY RATES
00085 -C           AFTER PHASES I, II, III, IV
00086 -C
00087 -      WRITE (17,1130) B(58)
00088 - 1130 FORMAT(≠0≠,9X,≠OVERWINTER≠,9X,≠I - II≠,5X,≠DF,GF≠,67X,F5.3)
00089 -      WRITE(17,1140) B(59)
00090 - 1140 FORMAT(≠ ≠,27X,≠II - III≠,4X,≠DF,GF≠,67X,F5.3)
00091 -      WRITE (17,1150) B(60)
00092 - 1150 FORMAT(≠ ≠,27X,≠III - IV    DF,GF≠,67X,F5.3)
00093 -      WRITE (17,1155) B(61)
00094 -1155  FORMAT (≠ ≠,27X,≠IV-    ≠,5X,≠DF,GF≠,67X,1F5.3)
00095 -C
00096 -C           WRITE NOMINAL EGG MASS SIZE
00097 -C           PHASES I, II, III, IV
00098 -C
00099 -      WRITE(17,1160) B(53)
00100 - 1160 FORMAT(≠  ≠,24(≠-≠)/≠0  NOMINAL EGG MASS SIZE≠,8X,
00101 -     C≠I≠,7X,≠DF,GF≠,82X,F5.1)
00102 -      WRITE (17,1170) B(54)
00103 - 1170 FORMAT(≠ ≠,30X,≠II≠,7X,≠DF,GF≠,82X,F5.1)
00104 -      WRITE(17,1180) B(55)
00105 - 1180 FORMAT(≠ ≠,30X,≠III≠,6X,≠DF,GF≠,82X,F5.1)
00106 -      WRITE (17,1190) B(56)
00107 -1190  FORMAT (31X,≠IV≠,7X,≠DF,GF≠,82X,1F5.1)
00108 -      RETURN
00109 -      END
EOD ON INPUT UNIT
00001 -      SUBROUTINE TABLE3(X,B)
00002 -      DIMENSION X(1),B(1)
00003 -C
00004 -C           COMPLETE TABLE 3 BY WRITING THE PHASE-SPECIFIC MEAN
00005 -C           EGG DENSITIES FOR PHASES I, II, III, IV, AND THE
00006 -C           AND THE OUTBREAK REDISTRIBUTION COEFFICIENT
00007 -C
00008 -      WRITE(17,3000) (X(I),I=1,4)
00009 - 3000 FORMAT(≠0≠,135(≠-≠)/≠- PHASE SPECIFIC≠,
00010 -     C≠ MEAN EGG DENSITIES:   I=≠,F7.3,≠   II=≠,F7.3,
00011 -     C≠   III=≠,F7.3,≠   IV=≠,1F7.3)
00012 -      WRITE (17,2999) B(62)
00013 - 2999 FORMAT (≠0REDISTRIBUTION COEFFICIENT FOR THE≠,
00014 -     C≠ OUTBREAK:  ≠,F7.3)
00015 -      RETURN
00016 -      END
EOD ON INPUT UNIT
00001 -      SUBROUTINE TABLE12(B)
00002 -C
00003 -C           THIS ROUTINE WRITES THE TWO SPECIALLY FORMATTED OUTBREAK
00004 -C           SUMMARIES REFERRED TO AS TABLES 1 AND 2.
00005 -C           TABLE 1 GIVES THE INPUT/OUTPUT VARIABLE VALUES, BY PHASE,
00006 -C           OVER THE COURSE OF THE OUTBREAK.  TABLE 2 CONDENSES THIS
00007 -C           INFORMATION FURTHER AND GIVES THE MORTALITY AND TOP KILL
00008 -C           EXPECTIONS WHICH COMPRISE THE STAND POST-OUTBREAK MODEL.
00009 -C
00010 -      DIMENSION B(1)
00011 -      DIMENSION ISPECIES(6),IC(15,3),A(15,26),C(15,5),AMORT(14,9)
00012 -      DIMENSION WT(15)
00013 -      DIMENSION IPHASE(4),BB(2,12)
00014 -      DATA((IPHASE(I),I=1,4)=≠I   ≠,≠II  ≠,≠III ≠,≠IV  ≠)
00015 -      DATA ((ISPECIES(I),I=1,6)=≠DOUG≠,≠LAS-≠,≠FIR ≠,≠ GRA≠,
00016 -     C ≠NO F≠,≠IR  ≠)
00017 -C
00018 -C           OBTAIN TIME AND DATE
00019 -C
00020 -      TIME=0.
00021 -      DATE=0.
00022 -      EM=0.
00023 -      CALL XREQ(33B,0,0,EM,TIME)
00024 -      CALL XREQ(32B,0,0,EM,DATE)
00025 -C
00026 -C           OBTAIN THE TOP-KILL (AMORT) AND SECONDARY
00027 -C           MORTALITY (B9) DISTRIBUTIONS FOR THE MODEL
00028 -C           AMORT VALUES ARE READ IN AS FOLLOWS:
00029 -C           FROM LUN 13 (DOUGLAS FIR MORTALITY INFO.):
00030 -C           AMORT(I,J) I,J=1,...,7 CONTAIN FIRST 7 RECORDS
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00031 -C          BB(I,J) J=1,...6, I=1,2  CONTAIN LAST 2 RECORDS
00032 -C          FROM LUN 14 (GRAND FIR MORTALITY INFO.):
00033 -C          AMORT(I,J) J=1,...,7, I=8,...,14 CONTAIN FIRST 7 RECORDS
00034 -C          BB(I,J) J=7,...,12, I=1,2 CONTAIN LAST 2 RECORDS
00035 -C
00036 -C          I VARIES WITH PERCENT OF CROWN DEFOLIATED:
00037 -C           1 OR 8::0-15%: 2 OR 9::16-35%: 3 OR 10::36-65%:
00038 -C           4 OR 11::66-85%; 5 OR 12::86-95%; 6 OR 13::96-99.5%:
00039 -C           7 OR 14::99.5-100%
00040 -C          VALUES READ IN FOR AMORT:
00041 -C          AMORT(I,1)=EXPECTATION OF DIRECT MORTALITY
00042 -C          FOLLOWING ARE CONDITIONAL EXPECTATIONS, GIVEN
00043 -C          SURVIVAL OF DIRECT MORTALITY
00044 -C          AMORT(I,2)=NO TOP KILL DAMAGE
00045 -C          AMORT(I,3)=LEADER KILL
00046 -C          AMORT(I,4)=1-10% TOP KILL
00047 -C          AMORT(I,5)=1-25% TOP KILL
00048 -C          AMORT(I,6)=1-50% TOP KILL
00049 -C          AMORT(I,7)=1-99% TOP KILL
00050 -C
00051 -C          VALUES OF AMORT AS RECALCULATED FOR OUTPUT
00052 -C
00053 -C          AMORT(I,1)=EXPECTATION OF DIRECT MORTALITY FROM DFTM
00054 -C          AMORT(I,2)=EXPECTATION OF SECONDARY MORT., ALL CAUSES
00055 -C          AMORT(I,3)=EXPECTATION OF TOP KILL, ALL DEGREES
00056 -C          AMORT(I,4)=EXPECTATION OF GROWTH REDUCTION ONLY
00057 -C          AMORT(I,5)=EXPECTATION OF LEADER KILL ONLY
00058 -C          AMORT(I,6)=EXPECTATION OF 1-10% TOP KILL
00059 -C          AMORT(I,7)=EXPECTATION OF 11-25% TOP KILL
00060 -C          AMORT(I,8)=EXPECTATION OF 26-50% TOP KILL
00061 -C          AMORT(I,9)=EXPECTATION OF 51-99% TOP KILL
00062 -C
00063 -C          FOR BB ARRAY I=1 SIGNIFIES SECONDARY MORTALITY
00064 -C          DUE TO BARK BEETLE
00065 -C          I=2 SIGNIFIES SECONDARY MORTALITY DUE TO OTHER CAUSES
00066 -C          BB(I,J=1 OR 7)=EXPECT. OF SECOND. MORT.,GIVEN
00067 -C          NO TOP KILL DAMAGE
00068 -C          BB(I,J=2 OR 8)=EXPECT. OF SECOND. MORT., GIVEN
00069 -C          LEADER KILL
00070 -C          BB(I,J=3 OR 9)=EXPECT. SECOND. MORT. GIVEN 0-10% TOP KILL
00071 -C          BB(I,J=4 OR 10)=EXPECT. SECOND. MORT. GIVEN 11-25% TOP KILL
00072 -C          BB(I,J=5 OR 11)=EXPECT. SECOND. MORT. GIVEN 26-50% TOP KILL
00073 -C          BB(I,J=6 OR 12)=EXPECT. SECOND. MORT. GIVEN 51-99% TOP KILL
00074 -C          BB ARRAY IS NOT OUTPUT BUT USED TO RECALCULATE THE
00075 -C          AMORT OUTPUT MATRIX
00076 -C
00077 -C
00078 -C
00079 -       REWIND 13
00080 -       REWIND 14
00081 -       READ(13,7000)((AMORT(I,J),J=1,7),I=1,7)
00082 -       READ(13,7001) ((BB(I,J),J=1,6),I=1,2)
00083 -       READ(14,7000)((AMORT(I,J),J=1,7),I=8,14)
00084 -       READ(14,7001)((BB(I,J),J=7,12),I=1,2)
00085 - 7000 FORMAT(1F7.4,6F6.3)
00086 - 7001 FORMAT(1F7.4,5F6.3)
00087 -C
00088 -C          COMPUTE THE TOTAL SECONDARY MORTALITY FROM
00089 -C          ITS TWO COMPONENTS
00090 -C
00091 -       DO 770 J=1,12
00092 - 770   BB(1,J)=BB(1,J)+BB(2,J)-(BB(1,J)*BB(2,J))
00093 -C
00094 -C          SET UP POST-OUTBREAK EXPECTATIONS FROM INPUT DATA
00095 -C
00096 -       DO 100 I=1,14
00097 -C
00098 -C          TRANSFORM CUMULATIVE TOP-KILL EXPECTATIONS TO
00099 -C          EXPECTATIONS BY TOP-KILL CLASS
00100 -C
00101 -       DO 90 J=1,3
00102 -       JJ=8-J
00103 -       JJ1=JJ-1
00104 - 90    AMORT(I,JJ)=AMORT(I,JJ)-AMORT(I,JJ1)
00105 -C
00106 -C          REDUCE TOP-KILL EXPECTATIONS BY DIRECT MORTALITY
00107 -C
00108 -       DO 91 J=2,7
00109 - 91    AMORT(I,J)=AMORT(I,J)*(1.-AMORT(I,1))
00110 -       IR=13
00111 -       IF(I.LT.8) IR=7
```

```
00112 -C
00113 -C          REDUCE TOP-KILL EXPECTATIONS BY SECONDARY MORTALITY
00114 -C
00115 -       DO 92 J=1,6
00116 -       JJ=10-J
00117 -       JJ2=JJ-2
00118 -       JB=IB-J
00119 - 92    AMORT(I,JJ)=(1.-PB(1,JB))*AMORT(I,JJ2)
00120 -       SUM=0.
00121 -C
00122 -C          CALCULATE PROPORTION OF TREES WHICH SURVIVE
00123 -C          AND SUFFER SOME GROWTH REDUCTION
00124 -C
00125 -       DO 93 J=5,9
00126 - 93    SUM=SUM+AMORT(I,J)
00127 -       AMORT(I,3)=SUM
00128 -       AMORT(I,2)=1.-AMORT(I,1)-AMORT(I,3)-AMORT(I,4)
00129 - 100   CONTINUE
00130 -C
00131 -C          REWIND INPUT LUNS
00132 -C
00133 -       DO 777 I=1,12
00134 - 777   REWIND I
00135 -C
00136 -C           SET PARAMETERS FOR CROWN DEFOLIATION EQUATION
00137 -C
00138 -       P1=-22.579678
00139 -       P2=-22.996253
00140 -       P3=-598181961.0
00141 -C
00142 -C          INITIALIZE OUTPUT FORMAT CONTROL INDICES
00143 -C          J: PAGE NUMBER
00144 -C          I:LINE NUMBER ON PAGE
00145 -C          INDEX: TOTAL LINES PRINTED
00146 -C          INDEXLIM: TOTAL NUMBER OF TREE CLASSES
00147 -C          IFLAG: FULL PAGE FLAG, 15 LINES
00148 -C          JMPFLAG:1 INDICATES LINE NEEDS NEW PAGE
00149 -C          BECAUSE OF NEW SPECIES OR FOLIAGE COMPLEMENT
00150 -C
00151 -       INDEXLIM=P(57)
00152 -       J=0
00153 -       INDEX=0
00154 -       JMPFLAG=0
00155 -C
00156 -C          NEW PAGE: RESET LINE COUNTERS
00157 -C
00158 - 1     I=0
00159 -       IFLAG=0
00160 -C
00161 -C           BEGIN NEW LINE: INCREMENT LINE COUNTERS
00162 -C
00163 - 2     I=I+1
00164 -       INDEX=INDEX+1
00165 -C
00166 -C          READ IN THE RESULTS OF THE FOUR YEAR OUTBREAK SIMULATION
00167 -C          RUN.  THE FOLLOWING CROSS-REFERENCE GUIDE IDENTIFIES
00168 -C          LOCAL VARIABLES.
00169 -C          LOCAL     DESCRIPTION          FLEX                  PHASE
00170 -C          -----     -----------          ----                  -----
00171 -C          IC(I,1)   HOST SPECIES         Z(6) IN S0            ALL
00172 -C          IC(I,2)   TREE CLASS NO.       J, COUNTER FOR P      ALL
00173 -C          IC(I,3)   LINE INDICATOR FOR AMORT TABLE
00174 -C
00175 -C          C(I,1)    NOMINAL % NEW FOL.   Z(2) IN S0            ALL
00176 -C          C(I,2)    NOMINAL TOTAL FOL.   Z(3) IN S0            ALL
00177 -C          C(I,3)    ACTUAL NEW FOL.      X(5) IN S0            I
00178 -C          C(I,4)    ACTUAL OLD FOL.      X(6) IN S0            I
00179 -C          C(I,5)    %CROWN DEFOLIATION
00180 -C
00181 -C          WT(I)     WEIGHTING FACTOR     Z(5) IN S0            ALL
00182 -C
00183 -C          A(I,1)    NO. OF TREES         Z(4) IN S0            ALL
00184 -C          A(I,2)    NO. OF VIABLE EGGS   X(7) IN S0            I
00185 -C          A(I,3)    TOTAL FOLIAGE        X(5)+X(6) IN S0       I
00186 -C          A(I,4)    ACTUAL % NEW FOL.                          I
00187 -C          A(I,5)    % DEFOLIATION        FROM Y(2) IN S1       I
00188 -C          A(I,6)    EGGS LAID            Y(3) IN S1            I
00189 -C          A(I,7)    REDIST. EGGS         G(2) IN S0            I
00190 -C          A(I,8)    NO. OF VIABLE EGGS   X(7) IN S0            II
00191 -C          A(I,9)    TOTAL FOLIAGE        X(5)+X(6) IN S0       II
```

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00192 -C          A(I,10)   ACTUAL % NEW FOL.                              II
00193 -C          A(I,11)   % DEFOLIATION        FROM Y(2) IN S1          II
00194 -C          A(I,12)   EGGS LAID            Y(3) IN S1               II
00195 -C          A(I,13)   REDIST. EGGS         G(2) IN S0               II
00196 -C          A(I,14)   NO. OF VIABLE EGGS   X(7) IN S0               III
00197 -C          A(I,15)   TOTAL FOLIAGE        X(5)+X(6) IN S0          III
00198 -C          A(I,16)   ACTUAL % NEW FOL.                             III
00199 -C          A(I,17)   % DEFOLIATION        FROM Y(2) IN S1          III
00200 -C          A(I,18)   EGGS LAID            Y(3) IN S1               III
00201 -C          A(I,19)   REDIST. EGGS         G(2) IN S0               III
00202 -C          A(I,20)   NO. OF VIABLE EGGS   X(7) IN S0               IV
00203 -C          A(I,21)   TOTAL FOLIAGE        X(6)+X(5) IN S0          IV
00204 -C          A(I,22)   ACTUAL % NEW FOL.                             IV
00205 -C          A(I,23)   % DEFOLIATION        FROM Y(2) IN S1          IV
00206 -C          A(I,24)   EGGS LAID            Y(3) IN S1               IV
00207 -C          A(I,25)   REDIST. EGGS         G(2) IN S0               IV
00208 -C          A(I,26)   % OF TREE NOT DEFOLIATED                      ALL
00209 -C
00210 -       READ(1,1001) IC(I,1),A(I,1),WT(I),C(I,1),C(I,2),C(I,3),C(I,4),
00211 -      C   A(I,2),IC(I,2)
00212 - 1001 FORMAT (I2,7F11.5,I3)
00213 -       A(I,3)=C(I,3)+C(I,4)
00214 -       A(I,4)=100.*C(I,3)/A(I,3)
00215 -       READ(2,1002) C(I,4),A(I,6)
00216 - 1002 FORMAT (12X,2F12.6)
00217 -       A(I,5)=100.0-100.0*C(I,4)/C(I,2)
00218 -       READ(3,1003) A(I,7)
00219 - 1003 FORMAT(1F12.6)
00220 -       READ(4,1004) C(I,3),C(I,4),A(I,8)
00221 - 1004 FORMAT (46X,3F11.5,3X)
00222 -       A(I,9)=C(I,3)+C(I,4)
00223 -       A(I,10)=C(I,3)*100./A(I,9)
00224 -       READ(5,1002) C(I,4),A(I,12)
00225 -       A(I,11)=100.0-C(I,4)*100.0/C(I,2)
00226 -       READ(6,1003) A(I,13)
00227 -       READ(7,1004) C(I,3),C(I,4),A(I,14)
00228 -       A(I,15)=C(I,3)+C(I,4)
00229 -       A(I,16)=C(I,3)*100./A(I,15)
00230 -       READ(8,1002) C(I,4),A(I,18)
00231 -       A(I,17)=100.0-C(I,4)*100.0/C(I,2)
00232 -       READ(9,1003) A(I,19)
00233 -       READ (10,1004) C(I,3),C(I,4),A(I,20)
00234 -       A(I,21)=C(I,3)+C(I,4)
00235 -       A(I,22)=C(I,3)*100.0/A(I,21)
00236 -       READ (11,1002) C(I,4),A(I,24)
00237 -       A(I,23)=100.0-C(I,4)*100.0/C(I,2)
00238 -       READ (12,1003) A(I,25)
00239 -C
00240 -C          CALCULATE MAXIMUM % OF FOLIAGE WHICH SURVIVED INTACT
00241 -C
00242 -       X1=FMAX(A(I,5),A(I,11))
00243 -       X2=FMAX(A(I,17),A(I,23))
00244 -       A(I,26)=100.-FMAX(X1,X2)
00245 -C
00246 -C          IF FIRST LINE, GO WRITE PAGE HEADER
00247 -C
00248 -       IF (I.EQ.1) GO TO 4
00249 -C
00250 -C          CHECK FOR NEW HOST SPECIES OR DIFFERENT NOMINAL
00251 -C          FOLIAGE COMPLEMENT.  IF DIFFERENT, SET FLAG AND GO TO 3:
00252 -C          START NEW PAGE
00253 -C
00254 -       IF (IC(I-1,1).NE.IC(I,1)) JMPFLAG=1



00255 -       INC1=IFIX(100.*C(I-1,1)+0.5)
00256 -       INC2=IFIX(100.*C(I,1)+.5)
00257 -       IF (INC1.NE.INC2) JMPFLAG=1
00258 -       IF(JMPFLAG.EQ.1) GO TO 3
00259 -C
00260 -C          IF LAST LINE ON PAGE, SET IFLAG=1: WRITE LINE.
00261 -C
00262 -       IF(I.EQ.15) IFLAG=1
00263 -C
00264 -C          COMPUTE CROWN DEFOLIATION AND FIND ASSOCIATED LINE
00265 -C          OF MORTALITY AND TOP-KILL TABLE (AMORT)
00266 -C
00267 - 5     CONTINUE
00268 -       IF(A(I,17).GT.95.) GO TO 15
00269 -       T=(P1/(P2+P3**EXP(P1*A(I,17)/100.)))*100.
00270 -       GO TO 16
00271 - 15    T=96.9689+((A(I,17)-95.)/5.)**3.0311
```

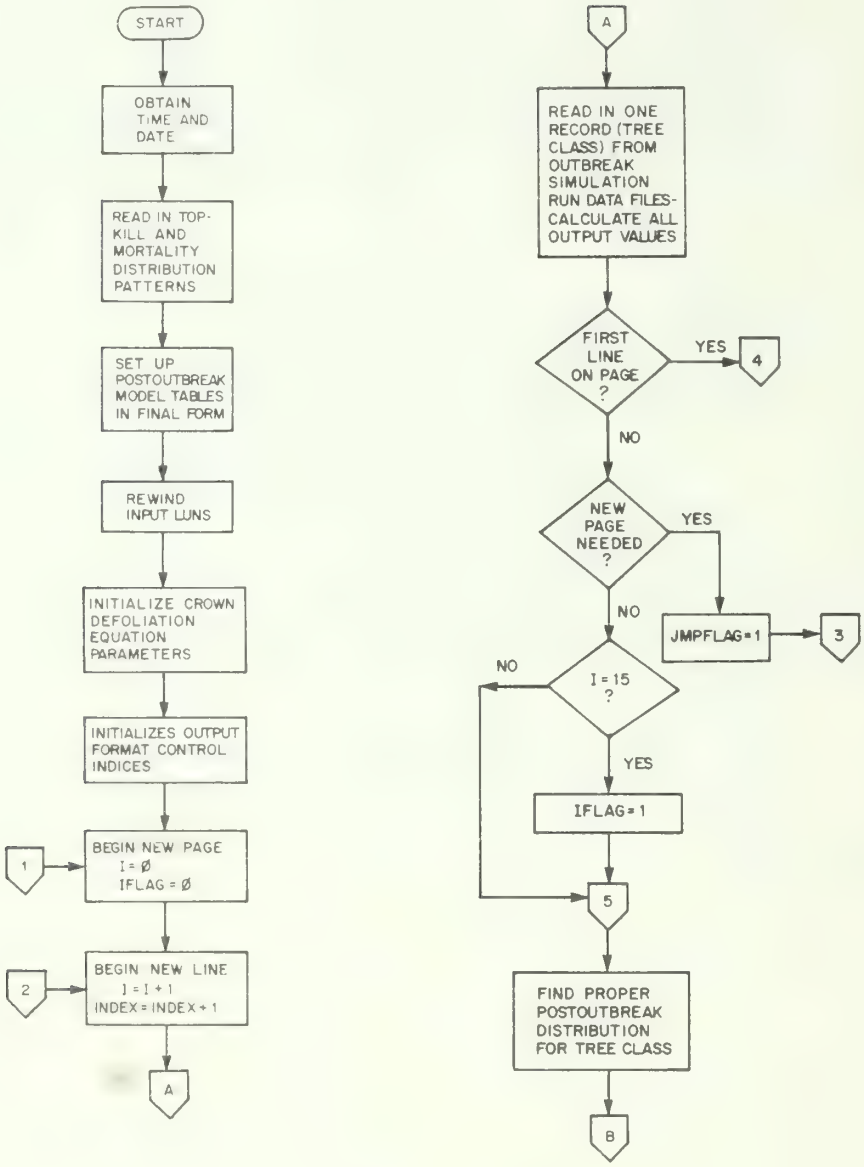
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00272 - 16    IF (T.LE.15.) IC(I,3)=1
00273 -       IF (T.GT.15..AND.T.LE.35.) IC(I,3)=2
00274 -       IF (T.GT.35..AND.T.LE.65.) IC(I,3)=3
00275 -       IF (T.GT.65..AND.T.LE.85.) IC(I,3)=4
00276 -       IF (T.GT.85..AND.T.LE.95.) IC(I,3)=5
00277 -       IF (T.GT.95..AND.T.LE.99.5) IC(I,3)=6
00278 -       IF (T.GT.99.5) IC(I,3)=7
00279 -       IF(IC(I,1).EQ.2) IC(I,3)=IC(I,3)+7
00280 -       C(I,5)=T
00281 -C
00282 -C         WRITE LINE(I) FOR TABLE 1 AND 2
00283 -C           ON UPPER HALF OF PAGE
00284 -C
00285 -       WRITE(15,2002) IC(I,2),(A(I,JJ),JJ=1,13)
00286 -       ICK=IC(I,3)
00287 -       WRITE(16,3002) IC(I,2),A(I,1),WT(I),A(I,2),A(I,5),A(I,11),
00288 -      CA(I,17),A(I,23),C(I,5),(AMORT(ICK,JJ),JJ=1,4)
00289 -C
00290 -C         CHECK FOR FULL PAGE AND EOD
00291 -C
00292 -       IF (IFLAG.EQ.1) GO TO 18
00293 -       IF (INDEX.LT.INDEXLIM) GO TO 2
00294 -C
00295 -C                     DOUBLE SPACE TO BOTTOM HALF OF PAGE
00296 -C
00297 - 3     CONTINUE
00298 -       IJ=16-I
00299 -       DO 12 JJ=1,IJ
00300 -       WRITE (15,2002)
00301 -       WRITE (16,3002)
00302 - 12    CONTINUE
00303 -C
00304 -C          FINISH PRESENT PAGE HALF
00305 -C
00306 - 18    WRITE (15,2003)
00307 -       WRITE (16,3003)
00308 -       IX=I-JMPFLAG
00309 -       IF (IFLAG.EQ.1) IX=15
00310 -       DO 10 II=1,IX
00311 -       WRITE (15,2002) IC(II,2),A(II,1),(A(II,JJ),JJ=14,25)
00312 -       ICK=IC(II,3)
00313 -       WRITE(16,3004) IC(II,2),A(II,1),WT(II),A(II,2),
00314 -      C(AMORT(ICK,JJ),JJ=5,9),
00315 -      CA(II,26),A(II,26),A(II,26)
00316 - 10    CONTINUE
00317 -       DO 200 K1=1,4
00318 -       WRITE(18,10000) J,(ISPECIES(JJ),JJ=IS,IM),C(1,1),
00319 -      C COMP,TIME,IPHASE(K1),DATE
00320 -       K2=K1*5-4
00321 -       K4=6*K1+1
00322 -       DO 210 K2=1,IX
00323 -       WRITE(18,10100) IC(K2,2),A(K2,1),(A(K2,JJ),JJ=K3,K4)
00324 - 210   CONTINUE
00325 -       ENDFILE 18
00326 - 200   CONTINUE
00327 -       WRITE(22,20000) J,(ISPECIES(JJ),JJ=IS,IM),C(1,1),COMP,
00328 -      C TIME,DATE
00329 -       WRITE(22,21000)
00330 -       DO 220 K1=1,IX
00331 -       ICK=IC(K1,3)
00332 -       WRITE(22,21100) IC(K1,2),A(K1,2),A(K1,5),A(K1,11),
00333 -      C A(K1,17),C(K1,5),AMORT(ICK,1)
00334 - 220   CONTINUE
00335 -       ENDFILE 22
00336 -       WRITE(23,20000) J,(ISPECIES(JJ),JJ=IS,IM),C(1,1)
00337 -      C ,COMP,TIME,DATE
00338 -       WRITE(23,22000)
00339 -       DO 230 K1=1,IX
00340 -       ICK=IC(K1,3)
00341 -       WRITE(23,22100) IC(K1,2),A(K1,2),C(K1,5),
00342 -      C  (AMORT(ICK,KJJ),KJJ=1,4)
00343 - 230   CONTINUE
00344 -       ENDFILE 23
00345 -       WRITE(24,20000) J,(ISPECIES(JJ),JJ=IS,IM),C(1,1),
00346 -      C  COMP,TIME,DATE
00347 -       WRITE(24,23000)
00348 -       DO 240 K1=1,IX
00349 -       ICK=IC(K1,3)
00350 -       WRITE(24,23100) IC(K1,2),A(K1,2),AMORT(ICK,2),
00351 -      C  (AMORT(ICK,JJ),JJ=5,9)
00352 - 240   CONTINUE
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00353 -       ENDFILE 24
00354 -C
00355 -C           IF NO MORE DATA, CHECK JMPFLAG FOR RETURN.
00356 -C           IF MORE DATA, CHECK IFLAG FOR FULL PAGE.
00357 -C
00358 -       IF(INDEX.LT.INDEXLIM) GO TO 20
00359 -       IF(JMPFLAG.NE.1) RETURN
00360 -       GO TO 19
00361 - 20    IF(IFLAG.EQ.1) GO TO 1
00362 -C
00363 -C                    *** LINE(I) IS FIRST LINE OF NEXT PAGE.  ***
00364 -C                        REPLACE A(1,J) WITH A(I,J), J=1,26
00365 -C                        REPLACE IC(1,K) AND C(1,K) WITH
00366 -C                        IC(I,K) AND C(I,K),K=1,2
00367 -C
00368 - 19    CONTINUE
00369 -       DO 7 II=1,26
00370 -       A(1,II)=A(I,II)
00371 - 7     CONTINUE
00372 -       IC(1,1)=IC(I,1)
00373 -       IC(1,2)=IC(I,2)
00374 -       C(1,1)=C(I,1)
00375 -       C(1,2)=C(I,2)
00376 -C
00377 -C           WRITE OUT HEADER AND BEGIN NEW PAGE
00378 -C
00379 - 4     CONTINUE
00380 -       J=J+1
00381 -       I=1
00382 -       JMPFLAG=0
00383 -       IS=1
00384 -       IF (IC(1,1).EQ.2) IS=4
00385 -       IM = IS+2
00386 -       COMP=100.-C(1,1)
00387 -       WRITE (15,2001) J,TIME,DATE,(ISPECIES(JJ),JJ=IS,IM),C(1,1),COMP
00388 -       WRITE (16,3001) J,TIME,DATE,(ISPECIES(JJ),JJ=IS,IM),C(1,1),COMP
00389 -       GO TO 5
00390 -C
00391 -C  ***** FORMAT STATEMENTS *****
00392 -C
00393 - 2001 FORMAT(≠1≠,9X,≠TABLE 1.≠,I2,≠:   INPUT-OUTPUT VARIABLE≠
00394 -     C≠ VALUES OVER THE OUTBREAK CYCLE≠,32X,2(2X,A8),//
00395 -     C,28X,≠FOR THE ≠,3A4,
00396 -     CX,F6.3,≠ / ≠,F6.3,≠ TREE CLASSES≠///42X,≠PHASE I≠,49X,
00397 -     C≠PHASE II≠/30X,≠INPUTS≠,21X,≠OUTPUTS≠,21X,≠INPUTS≠,21X,
00398 -     C≠OUTPUTS≠/≠ ≠,129(≠-≠)/≠0 TREE    NUMBER OF ≠,2(≠  VIAB≠
00399 -     C≠LE   TOTAL   PERCENT  DEFOLIA-  VIABLE   REDIS-  ≠),
00400 -     C/≠  CLASS     STEMS   ≠,2(≠   EGGS   FOLIAGE    NEW≠,6X,
00401 -     C≠TION    EGGS   TRIBUTED ≠)/≠   NO.≠,14X,2(10X,≠BIOMASS  ≠
00402 -     C≠FOLIAGE≠,13X,≠LATD     EGGS   ≠)/29X,2(≠   (NO.)  ≠
00403 -     C≠(GRAMS)     (%)       (%)       (NO.)     (NO.)  ≠)/≠ ≠,
00404 -     C129(≠-≠))
00405 -C
00406 -C
00407 - 2002 FORMAT(≠0  ≠,I3,5X,F8.3,X,2(X,6(F7.3,2X),X))
00408 - 2003 FORMAT(≠0≠,129(≠-≠)/42X,≠PHASE III≠,47X,≠PHASE IV≠/≠ ≠,
00409 -     C 129(≠-≠))
00410 -C
00411 -C
00412 - 3001 FORMAT(≠1≠,9X,≠TABLE 2.≠,I2,≠:   OUTBREAK DEFOLIATION SUMMARY≠,
00413 -     C≠ AND THE EXPECTED MORTALITY AND GROWTH REDUCTION≠,
00414 -     C14X,2(2X,A8),//,35X,≠FOR THE ≠,
00415 -     C3A4,X,F6.3,≠ / ≠,F6.3,≠ TREE CLASSES≠///X,125(≠-≠)/
00416 -     C≠  TREE   NUMBER  WEIGHT  INITIAL :     MODEL BRANCH:≠,
00417 -     C17X,≠PERCENT OF :  PROPORTION OF TREES RECEIVING:≠/
00418 -     C≠  CLASS    OF    FACTOR   VIABLE :  PERCENT DEFOLIATION≠,
00419 -     C≠ BY PHASE≠,8X,≠TREE    :≠,45(≠-≠)/
00420 -     C≠   NO.    TREES   PER     EGGS  :≠,74(≠-≠),≠   TOTALLY  :  ≠,
00421 -     C≠DIRECT    SECONDARY     TOP   ONLY GROWTH≠/
00422 -     C18X,≠TREE   I :   I≠,7X,≠II≠,7X,≠III≠,6X,≠IV    ≠,
00423 -     C≠DEFOLIATED : MORTALITY  MORTALITY     KILL   REDUCTION≠/
00424 -     CX,125(≠-≠))
00425 -C
00426 - 3002 FORMAT (≠0  ≠,I3,3X,2(F6.1,2X),X,F7.3,3X,
00427 -     CF6.3,2X,4(F7.3,2X),2X,4(F7.4,4X))
00428 -C
00429 -
00430 - 3003 FORMAT(≠0≠,120(≠-≠)/≠  TREE   NUMBER  WEIGHT  INITIAL :≠,
00431 -     C6X,≠PROPORTION OF TREES BY≠,7X,≠:  GROWTH IN SURVIVING   :≠,X,
00432 -     C≠DIAMETER GROWTH IN≠/
00433 -     C≠  CLASS    OF    FACTOR   VIABLE : PERCENT REDUCTION IN ≠,
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00434 -      C≠CROWN HEIGHT : TREES WITH NO TOP KILL : TREES WITH TOP KILL≠/
00435 -      C≠    NO.     TREES     PER      EGGS  : ≠,33(≠-≠),≠ :    ≠,
00436 -      C≠PERCENT OF NOMINAL    : ≠,19(≠-≠)/
00437 -      C18X,≠TREE    PHASE I :  0.0     5.0    17.5    37.5     70.0 : ≠,
00438 -      C≠DIAMETER    HEIGHT       : PERCENT OF NOMINAL≠/X,120(≠-≠))
00439 - 3004 FORMAT(≠0  ≠,I3,3X,F6.1,3X,F5.1,3X,F5.2,3X,4(F6.4,X),X,
00440 -      CF6.4,3X,2(F6.2,4X),10X,F6.2)
00441 -
00442 -10000 FORMAT (≠ TABLE 1.≠,I2,≠:  INPUT-OUTPUT VARIABLE VALUES ≠,
00443 -      C ≠OVER THE OUTBREAK≠/5X,≠CYCLE FOR THE ≠,3A4,F5.2,
00444 -      C ≠/≠,F5.2,≠ TREE CLASSES.≠/57X,A8/35X,≠PHASE ≠,A3,
00445 -      C 13X,A8/1X,13(≠-≠),≠[-------- INPUTS -------]≠,
00446 -      C ≠[------- OUTPUTS --------]≠/≠ TREE  NUMBER  INITIAL  TOTAL≠,
00447 -      C ≠  PERCENT   DEFOLIA VIABLE    RECIS-≠/≠ CLASS    OF     VIA≠,
00448 -      C ≠BLE  FOLIAGE    NEW      -TION    EGGS    TRIBUTED ≠/≠  NO.≠,
00449 -      C ≠    STEMS    EGGS   BIOMASS FOLIAGE≠,11X,≠LAID      EGGS≠/,
00450 -      C 16X,≠(NO.)   (GRAMS)    (%)≠,6X,≠(%)     (NO.)     (NO.)≠/,
00451 -      C 1X,64(≠-≠))
00452 -10100 FORMAT (1X,I3,2X,F7.2,1X,6(1X,F7.3))
00453 -20000 FORMAT(≠ TABLE 2.≠,I2,≠:  OUTBREAK DEFOLIATION SUMMARY ≠,
00454 -      C≠AND THE ASSOCIATED≠/5X,≠MORTALITY PROBABILITIES FOR THE ≠
00455 -      C,3A4,F5.2,≠/≠,F5.2/5X,≠TREE CLASSES.≠,22X,2(2X,A8)/)
00456 -21000 FORMAT(≠ ------ A: DEFOLIATION SUMMARY ≠,35(≠-≠)/≠ TREE ≠,
00457 -      C≠ INITIAL≠,5X,≠BRANCH PERCENT      PERCENT OF  EXPECTATION≠,
00458 -      C/≠ CLASS  VIABLE  DEFOLIATION BY PHASE≠,7X,≠TREE≠,8X,≠OF≠/,
00459 -      C≠  NO.    EGGS  ≠,22(≠-≠),≠    TOTALLY     DIRECT≠/7X,
00460 -      C≠PHASE I     I       II       III    DEFOLIATED   MORTALITY≠,
00461 -      C/≠ ≠,64(≠-≠))
00462 -21100 FORMAT(2X,I3,1X,4(1X,F7.3),2X,F7.3,5X,F7.4)
00463 -22000 FORMAT(≠ ------ B: MORTALITY PROBABILITIES ≠,31(≠-≠)/,
00464 -      C≠ TREE  INITIAL  PERCENT≠,13X,≠EXPECTATION OF≠/≠ CLASS≠
00465 -      C,≠  VIABLE  OF TREE ≠,41(≠-≠)/≠  NO.     EGGS    DEFOL-≠,
00466 -      C≠    DIRECT    SECONDARY    TOP  NO TOP KILL≠/7X,≠PHASE I≠,
00467 -      C≠     IATED MORTALITY MORTALITY  KILL    DAMAGE≠/≠ ≠,64(≠-≠))
00468 -22100 FORMAT(1X,I3,3X,2(F7.3,2X),4(F7.4,2X))
00469 -23000 FORMAT (≠ ------ C: TOP KILL PROBABILITIES ≠,31(≠-≠)/,
00470 -      C≠ TREE  INITIAL≠/≠ CLASS  VIABLE≠,14X,≠EXPECTATION OF TOP≠,
00471 -      C≠ KILL≠/≠  NO.     EGGS  ≠,50(≠-≠)/7X,≠PHASE I     ANY     L≠,
00472 -      C≠ADER  1-10%  11-25%  26-50%  51-90% ≠/≠ ≠,64(≠-≠))
00473 -23100 FORMAT(1X,I3,3X,F7.3,2X,6(F7.4,1X))
00474 -      END
EOF ON INPUT UNIT
```

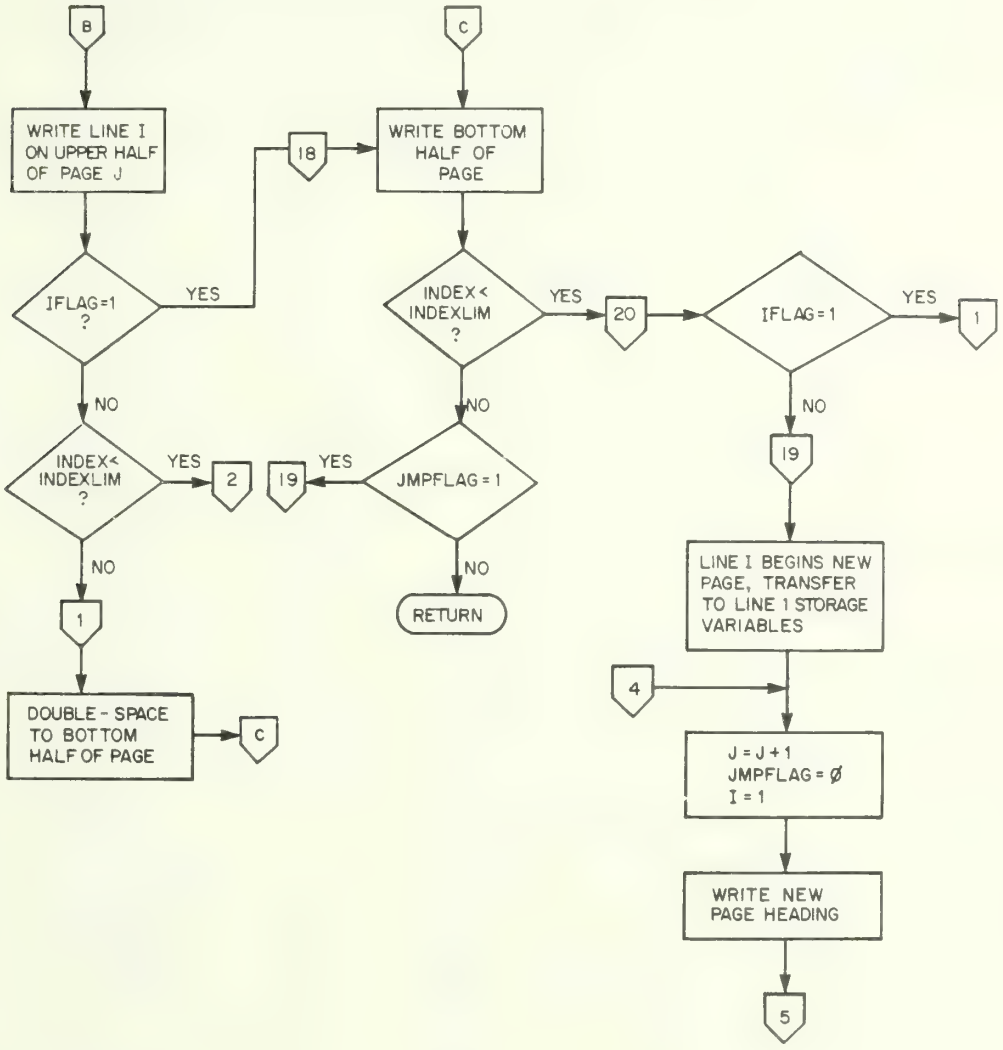
```
00001 -       SUBROUTINE TABLE32(B)
00002 -       DIMENSION B(1)
00003 -C
00004 -C            WRITE THE DESTRUCTION/CONSUMPTION RATIOS AND
00005 -C            INDIVIDUAL BIOMASS GROWTH RATES ON TABLE 3, LUN 17
00006 -C
00007 -       WRITE (17,1500) (B(J),J=7,12)
00008 - 1500 FORMAT(≠  ≠,24(≠-≠)/≠0 DESTRUCTION/CONSUMPTION≠/
00009 -      C≠ ≠,10X,≠RATIOS≠/≠  ≠,24(≠-≠)//≠0≠,8X,≠NEW FOLIAGE≠,
00010 -      C8X,≠I,II,III     DF,GF≠,5X,6(F6.3,X))
00011 -       WRITE (17,1550) (B(J),J=13,18)
00012 - 1550 FORMAT(≠0≠,8X,≠OLD FOLIAGE≠,8X,≠I,II,III     DF,GF≠,5X,
00013 -      C6(F6.3,X))
00014 -       WRITE (17,1600) B(22),B(22),B(22),B(23),B(24),B(24)
00015 - 1600 FORMAT(≠  ≠,24(≠-≠)/≠0≠,5X,≠INDIVIDUAL≠//≠     BIOMASS≠
00016 -      C≠ GROWTH RATE≠,5X,≠I,II,III     DF,GF≠,5X,6(F6.4,X))
00017 -       RETURN
00018 -       END
00019 -C
00020 -C
00021 -C
00022 -C
00023 -C
00024 -       SUBROUTINE S2(X,KP,F0404)
00025 -       DIMENSION IBOUT(8),IXOUT(8),XOUT(4)
00026 -       DIMENSION X(1)
00027 -       EQUIVALENCE (IBOUT(1),X1),(IBOUT(3),X2),(IBOUT(5),X3)
00028 -       EQUIVALENCE (IBOUT(7),X4),(IXOUT(1),XOUT(1)),(IXOUT(3),XOUT(2))
00029 -       EQUIVALENCE (IXOUT(5),XOUT(3)),(IXOUT(7),XOUT(4))
00030 -C
00031 -C            AT KP=0, WRITE CURRENT STATE VARIABLES ON LUNS 21 AND 25:
00032 -C            AT ALL OTHER TIME STEPS WRITE UPDATED
00033 -C            VALUES ONLY ON 21 AND 25
00034 -C
00035 -       X1=X(1)+(F(1,1)-F(1,2))*0.10
00036 -       X2=X(2)+(F(2,2)+F(1,2))*0.10
00037 -       X3=X(3)+F(3,3)*0.10
00038 -       X4=X(4)+F0404*0.10
00039 -       IF(KP.EQ.0) WRITE(21,1000) X(1),X(2),X(3),X(4)
00040 -       WRITE (21,1000) X1,X2,X3,X4
00041 - 1000 FORMAT (4(2X,F14.7))
00042 -       IF (KP.EQ.9) WRITE (21,1000)
00043 -       DO 1 I=1,4
00044 - 1     XOUT(I)=X(I)
00045 -       IF(KP.EQ.0) BUFFER OUT(25,1) (IXOUT(1),IXOUT(8))
00046 -       CALL UNITST(25,IB25)
00047 -       IF(KP.NE.9) BUFFER OUT(25,1) (IBOUT(1),IBOUT(8))
00048 -       RETURN
00049 -       END
EOF ON INPUT UNIT
```

Subroutine TABLE12 flowchart



Note: The numbers inside symbol ⬠ are statement labels in the code for the subroutine TABLE12.

Subroutine TABLE12 flowchart (continued)



APPENDIX B VERSION 2.2 VERIFICATION OUTPUT

	Page
Model parameterization	77
Simulation output	77

STATE VARIABLES 4 | ITY PRINT INTERVAL 1 | CONTROL INPUT LUN 54 | CONTROL OUTPUT LUN 61
INITIAL TIME 0 | DATA DUMP INTERVAL 1 | LINE PRINTER LUN 1 | FUNCTION INPUT LUN 52
TERMINATION 10 | LP PRINT INTERVAL 1 | DATA DUMP LUN 2
RESOLUTION RATIO 1

	(1)	(2)	(3)	(4)						
INITIAL X	5.0400E 01	9.3600E 01	7.5000E 01	0E 00						
R CONSTANTS	0E 00	0E 00	0E 00	0E 00	1.0000E-03	1.0000E-03	0E 00	0E 00	0E 00	0E 00
	1.0000E-03	1.0000E-03	1.0000E 00	8.0000E-01	5.0000E-01	1.0000E-01				
B CONSTANTS	2.0000E-02	2.0000E-02	2.0000E-02	2.0000E-02	2.0000E-02	2.0000E-02	5.4000E 00	6.2500E 00	6.2500E 00	2.7100E 00
	2.2700E 00	2.0000E 00	5.4000E 00	6.2500E 00	6.2500E 00	3.6900E 00	3.2900E 00	3.0000E 00	1.1900E 00	8.1000E-02
	1.0000E-01	1.1470E-01	8.8600E-02	6.2500E-02	1.9700E-01	5.2063E 01	2.0000E-02	1.0000E-02	2.0000E 00	5.0000E-01
	3.5000E 01	1.4400E 02	0E 00	6.2000E-01	2.0000E 02	0E 00	6.0000E-01			

FLOW FUNCTIONS 0 * = DEFINED

	1	2	3	4
F(1,J)	*	*	0	0
F(2,J)	0	*	0	0
F(3,J)	0	0	*	0
F(4,J)	0	0	0	*

INDICES OF DEFINED G FUNCTIONS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19

INDICES OF DEFINED H FUNCTIONS

YCOMP SUBROUTINE IS DEFINED
?COMP SUBROUTINE IS UNDEFINED

TIME	Y(1)	Y(2)	Y(3)	Y(4)	G(1)	G(2)	G(3)	G(4)	G(5)	G(6)
	G(7)	G(8)	G(9)	G(10)	G(11)	G(12)	G(13)	G(14)	G(15)	G(16)
	G(17)	G(18)	G(19)							
0	50.400000	93.600000	75.000000	0	-0	-0	-0	-0	-0	-0
	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0
	-0	-0	-0							
1	50.400000	93.600000	75.000000	.197000	0	0	0	0	0	0
	0	0	0	0	0	0	.197000	0	0	0
	0	0	0							
2	47.402112	93.600000	61.280461	.620300	0	0	0	2.917888	0	.980000
	0	-0.182927	0	0	-13.719539	.114700	.423300	0	10.000000	2.917888
	0	0	0							
3	38.793482	93.600000	50.070598	1.953160	0	0	0	8.688631	0	.980000
	.200000	-0.182927	0	0	-11.209863	.114700	1.332859	0	10.000000	8.688631
	0	0	0							
4	16.439862	93.600000	40.911324	6.149978	0	0	0	22.353620	0	.980000
	.500000	-0.182927	0	0	-9.159274	.114700	4.196818	0	10.000000	22.353620
	0	0	0							
5	0	90.716618	30.084777	14.916209	0	0	0	16.439862	2.883382	.980000
	.900000	-0.264634	1.000000	0	-10.826547	.088600	8.766231	0	9.000000	18.433652
	1.000000	2.883382	0							
6	0	62.148494	12.047233	27.867146	0	0	0	0	28.568125	.978041
	1.000000	-0.199114	11.000000	-0.400443	-18.037544	.062500	12.950938	0	0	0
	10.000000	28.568125	0							
7	0	42.659848	9.648457	52.062684	0	0	0	0	19.488646	.978041
	1.000000	-0.199114	21.000000	0	-2.398777	.062500	24.195537	.070523	0	0
	10.000000	19.488646	0							
8	0	42.659848	3.666414	52.062684	0	0	0	0	0	0
	0	0	21.000000	-0.620000	-5.982043	0	0	1.000000	0	0
	0	0	0							
9	32.665473	42.659848	579.293334	52.062684	32.665473	0	0	0	0	0
	0	0	21.000000	157.000000	575.626921	0	0	1.000000	0	0
	0	0	0							
10	32.665473	42.659848	231.717334	52.062684	0	0	0	0	0	0
	0	0	0	-0.600000	-347.576000	0	0	1.000000	0	0
	0	0	0							

APPENDIX C VERSION 3.1 VERIFICATION INPUT AND OUTPUT

	Page
Inputs:	
LUN1	79
LUN13	79
LUN14	79
Outputs:	
Table 1	80
Table 2	82
Table 3	84
Table 4	85

LUN1

```
00001 - 2    1.0    1.0    35.0    144.0    50.40    93.60    0.1    1
00002 - 2    1.0    1.0    35.0    144.0    50.40    93.60    0.5    2
00003 - 2    1.0    1.0    35.0    144.0    50.40    93.60    1.0    3
00004 - 2    1.0    1.0    35.0    144.0    50.40    93.60    2.0    4
00005 - 2    1.0    1.0    35.0    144.0    50.40    93.60    3.0    5
00006 - 2    1.0    1.0    35.0    144.0    50.40    93.60    3.5    6
00007 - 2    1.0    1.0    35.0    144.0    50.40    93.60    4.0    7
00008 - 2    1.0    1.0    35.0    144.0    50.40    93.60    4.5    8
00009 - 2    1.0    1.0    35.0    144.0    50.40    93.60    5.0    9
00010 - 2    1.0    1.0    35.0    144.0    50.40    93.60    6.0   10
00011 - 2    1.0    1.0    35.0    144.0    50.40    93.60    8.0   11
00012 - 2    1.0    1.0    35.0    144.0    50.40    93.60   10.0   12
00013 - 1    1.0    1.0    30.0    100.0    30.0     70.0     0.1   13
00014 - 1    1.0    1.0    30.0    100.0    30.0     70.0     0.5   14
00015 - 1    1.0    1.0    30.0    100.0    30.0     70.0     1.0   15
00016 - 1    1.0    1.0    30.0    100.0    30.0     70.0     2.0   16
00017 - 1    1.0    1.0    30.0    100.0    30.0     70.0     3.0   17
00018 - 1    1.0    1.0    30.0    100.0    30.0     70.0     3.5   18
00019 - 1    1.0    1.0    30.0    100.0    30.0     70.0     4.0   19
00020 - 1    1.0    1.0    30.0    100.0    30.0     70.0     4.5   20
00021 - 1    1.0    1.0    30.0    100.0    30.0     70.0     5.0   21
00022 - 1    1.0    1.0    30.0    100.0    30.0     70.0     6.0   22
00023 - 1    1.0    1.0    30.0    100.0    30.0     70.0     8.0   23
00024 - 1    1.0    1.0    30.0    100.0    30.0     70.0    10.0   24
EOF ON INPUT UNIT
```

LUN13

```
00001 -0.000   0.879  0.073  0.048  0.048  0.048  0.048
00002 -0.000   0.762  0.143  0.072  0.072  0.072  0.095
00003 -0.009   0.555  0.191  0.222  0.222  0.254  0.254
00004 -0.028   0.457  0.257  0.171  0.171  0.286  0.286
00005 -0.173   0.475  0.175  0.075  0.075  0.200  0.350
00006 -0.477   0.462  0.308  0.076  0.076  0.076  0.230
00007 -0.923   0.462  0.308  0.076  0.076  0.076  0.230
00008 -0.068   0.000  0.034  0.333  0.250  0.667
00009 -0.076   0.049  0.000  0.143  0.000  0.667
EOF ON INPUT UNIT
```

LUN14

```
00001 -0.000   0.940  0.035  0.013  0.017  0.021  0.025
00002 -0.000   0.867  0.090  0.031  0.039  0.041  0.042
00003 -0.009   0.712  0.138  0.095  0.128  0.141  0.150
00004 -0.028   0.569  0.183  0.111  0.157  0.209  0.248
00005 -0.173   0.493  0.240  0.075  0.103  0.123  0.267
00006 -0.477   0.460  0.189  0.081  0.135  0.135  0.351
00007 -0.923   0.460  0.189  0.081  0.135  0.135  0.351
00008 -0.014   0.005  0.022  0.333  0.053  0.472
00009 -0.029   0.021  0.032  0.000  0.000  0.143
EOF ON INPUT UNIT
```

1/ The value 0.333 for this parameter was used for validation simulations. The updated value 0.030 should be substituted for any further use of this parameter.

TABLE 1. 1: INPUT-OUTPUT VARIABLE VALUES OVER THE OUTBREAK CYCLE 23:31:45 08/18/77

FOR THE GRAND FIR 35.000 / 65.000 TREE CLASSES

		PHASE I						PHASE II					
		INPUTS				OUTPUTS		INPUTS				OUTPUTS	
TREE CLASS NO.	NUMBER OF STEMS	VIABLE EGGS (NO.)	TOTAL FOLIAGE BIOMASS (GRAMS)	PERCENT NEW FOLIAGE (%)	DEFOLIATION (%)	VIABLE EGGS LAID (NO.)	REDISTRIBUTED EGGS (NO.)	VIABLE EGGS (NO.)	TOTAL FOLIAGE BIOMASS (GRAMS)	PERCENT NEW FOLIAGE (%)	DEFOLIATION (%)	VIABLE EGGS LAID (NO.)	REDISTRIBUTED EGGS (NO.)
1	1.000	.100	144.000	35.000	.083	1.488	1.488	.744	143.979	34.991	.626	8.081	8.081
2	1.000	.500	144.000	35.000	.414	7.439	7.439	3.719	143.896	34.953	3.128	40.406	40.406
3	1.000	1.000	144.000	35.000	.828	14.878	14.878	7.439	143.791	34.906	6.256	80.811	80.811
4	1.000	2.000	144.000	35.000	1.655	29.755	29.755	14.878	143.583	34.811	12.513	161.623	161.623
5	1.000	3.000	144.000	35.000	2.483	44.633	44.633	22.316	143.374	34.716	18.769	242.434	242.434
6	1.000	3.500	144.000	35.000	2.897	52.072	52.072	26.036	143.270	34.669	21.898	282.840	282.840
7	1.000	4.000	144.000	35.000	3.310	59.511	59.511	29.755	143.166	34.621	25.026	323.245	323.245
8	1.000	4.500	144.000	35.000	3.724	66.949	66.949	33.475	143.062	34.574	28.154	363.651	363.651
9	1.000	5.000	144.000	35.000	4.138	74.388	74.388	37.194	142.957	34.526	31.282	404.057	404.057
10	1.000	6.000	144.000	35.000	4.966	89.266	89.266	44.633	142.749	34.430	38.878	465.473	465.473
11	1.000	8.000	144.000	35.000	6.621	119.021	119.021	59.511	142.332	34.238	57.540	543.052	543.052
12	1.000	10.000	144.000	35.000	8.276	148.777	148.777	74.388	141.914	34.045	68.281	510.566	510.566

		PHASE III						PHASE IV					
1	1.000	3.232	143.842	34.929	1.922	3.525	3.525	.529	143.516	34.781	.467	.095	.095
2	1.000	16.162	143.212	34.642	9.610	17.626	17.626	2.644	141.578	33.888	2.337	.474	.474
3	1.000	32.325	142.423	34.280	19.219	35.253	35.253	5.288	139.157	32.738	4.674	.948	.948
4	1.000	64.649	140.847	33.545	40.324	62.045	62.045	9.307	126.172	31.892	14.688	1.668	1.668
5	1.000	96.974	139.270	32.792	53.323	36.926	36.926	5.539	104.178	35.480	29.028	.993	.993
6	1.000	113.136	138.482	32.410	46.510	14.843	14.843	2.226	115.705	33.429	20.201	.399	.399
7	1.000	129.298	137.693	32.023	45.504	8.359	8.359	1.254	117.407	33.161	18.778	.225	.225
8	1.000	145.460	136.905	31.632	40.543	2.282	2.282	.342	125.802	31.942	12.722	.061	.061
9	1.000	161.623	136.117	31.236	40.860	1.248	1.248	.187	125.264	32.015	13.057	.034	.034
10	1.000	186.189	128.619	31.568	43.673	.348	.348	.052	120.505	32.691	16.329	.009	.009
11	1.000	217.221	97.042	36.994	63.828	.098	.098	.015	86.404	39.715	40.001	.003	.003
12	1.000	204.226	78.869	42.087	71.615	.046	.046	.007	73.227	44.182	49.150	.001	.001

TABLE 1. 2: INPUT-OUTPUT VARIABLE VALUES OVER THE OUTBREAK CYCLE 23:31:45 08/18/77

FOR THE DOUGLAS-FIR 30.000 / 70.000 TREE CLASSES

		PHASE I						PHASE II					
		INPUTS				OUTPUTS		INPUTS				OUTPUTS	
TREE CLASS NO.	NUMBER OF STEMS	VIABLE EGGS (NO.)	TOTAL FOLIAGE BIOMASS (GRAMS)	PERCENT NEW FOLIAGE (%)	DEFOLIATION (%)	VIABLE EGGS LAID (NO.)	REDISTRIBUTED EGGS (NO.)	VIABLE EGGS (NO.)	TOTAL FOLIAGE BIOMASS (GRAMS)	PERCENT NEW FOLIAGE (%)	DEFOLIATION (%)	VIABLE EGGS LAID (NO.)	REDISTRIBUTED EGGS (NO.)
13	1.000	.100	100.000	30.000	.119	1.488	1.488	.744	99.982	29.987	.898	8.081	8.081
14	1.000	.500	100.000	30.000	.596	7.439	7.439	3.719	99.911	29.937	4.490	40.406	40.406
15	1.000	1.000	100.000	30.000	1.192	14.878	14.878	7.439	99.821	29.875	8.980	80.811	80.811
16	1.000	2.000	100.000	30.000	2.383	29.755	29.755	14.878	99.642	29.749	17.959	161.623	161.623
17	1.000	3.000	100.000	30.000	3.575	44.633	44.633	22.316	99.464	29.623	26.938	242.434	242.434
18	1.000	3.500	100.000	30.000	4.171	52.072	52.072	26.036	99.374	29.559	32.289	274.354	274.354
19	1.000	4.000	100.000	30.000	4.767	59.511	59.511	29.755	99.285	29.496	39.247	287.688	287.688
20	1.000	4.500	100.000	30.000	5.363	66.949	66.949	33.475	99.196	29.432	45.601	312.740	312.740
21	1.000	5.000	100.000	30.000	5.959	74.388	74.388	37.194	99.106	29.369	52.094	335.367	335.367
22	1.000	6.000	100.000	30.000	7.150	89.266	89.266	44.633	98.927	29.241	65.053	378.197	378.197
23	1.000	8.000	100.000	30.000	9.534	119.021	119.021	59.511	98.570	28.984	90.280	459.008	459.008
24	1.000	10.000	100.000	30.000	11.917	148.777	148.777	74.388	98.212	28.726	98.207	445.109	445.109

		PHASE III						PHASE IV					
13	1.000	3.232	99.865	29.906	2.745	3.525	3.525	.529	99.588	29.711	.600	.095	.095
14	1.000	16.162	99.327	29.525	13.723	17.626	17.626	2.644	97.942	28.529	3.002	.474	.474
15	1.000	32.325	98.653	29.044	27.446	35.253	35.253	5.288	95.883	26.994	6.005	.948	.948
16	1.000	64.649	97.306	28.062	65.568	49.354	49.354	7.403	54.596	36.934	48.047	1.327	1.327
17	1.000	96.974	95.959	27.052	73.009	40.592	40.592	6.089	46.039	41.375	56.135	1.091	1.091
18	1.000	109.742	92.868	27.089	80.135	40.707	40.707	6.106	37.845	47.509	64.336	1.094	1.094
19	1.000	115.075	84.866	28.413	86.642	37.817	37.817	5.673	30.362	56.004	71.664	1.016	1.016
20	1.000	125.096	77.559	29.861	94.962	36.412	36.412	5.462	20.794	75.771	81.156	.979	.979
21	1.000	134.147	70.092	31.653	100.000	16.511	16.511	2.477	11.400	100.000	89.484	.444	.444
22	1.000	151.279	55.189	36.678	80.590	8.485	8.485	1.273	37.321	47.993	63.133	.228	.228
23	1.000	183.603	26.178	62.869	91.553	.037	.037	.006	24.714	65.822	75.288	.001	.001
24	1.000	178.044	17.062	89.491	100.000	0	0	0	13.200	100.000	86.800	0	0

TABLE 2. 1: OUTBREAK DEFOLIATION SUMMARY AND THE EXPECTED MORTALITY AND GROWTH REDUCTION 23:31:45 08/18/77

FOR THE GRAND FIR 35.000 / 65.000 TREE CLASSES

TREE CLASS NO.	NUMBER OF TREES	WEIGHT FACTOR PER TREE	INITIAL VIABLE EGGS PHASE I	MODEL BRANCH: PERCENT DEFOLIATION BY PHASE I	II	III	IV	PERCENT OF TREE TOTALLY DEFOLIATED	PROPORTION OF TREES RECEIVING: DIRECT MORTALITY	SECONDARY MORTALITY	TOP KILL	ONLY GROWTH REDUCTION
1	1.0	1.0	.100	.093	.626	1.922	.467	.000	0	.0454	.0547	.9000
2	1.0	1.0	.500	.414	3.128	9.610	2.337	.000	0	.0454	.0547	.9000
3	1.0	1.0	1.000	.828	6.256	19.219	4.674	.000	0	.0454	.0547	.9000
4	1.0	1.0	2.000	1.655	12.513	40.324	14.688	.034	0	.0454	.0547	.9000
5	1.0	1.0	3.000	2.483	18.769	53.323	29.028	.635	0	.0454	.0547	.9000
6	1.0	1.0	3.500	2.897	21.898	46.510	20.201	.137	0	.0454	.0547	.9000
7	1.0	1.0	4.000	3.310	25.026	45.504	18.778	.109	0	.0454	.0547	.9000
8	1.0	1.0	4.500	3.724	28.154	40.543	12.722	.036	0	.0454	.0547	.9000
9	1.0	1.0	5.000	4.138	31.282	40.860	13.057	.038	0	.0454	.0547	.9000
10	1.0	1.0	6.000	4.966	38.978	43.673	16.329	.072	0	.0454	.0547	.9000
11	1.0	1.0	8.000	6.621	57.540	63.828	40.001	6.407	0	.0454	.0547	.9000
12	1.0	1.0	10.000	8.276	68.281	71.615	49.150	28.310	0	.0452	.1247	.8301

TREE CLASS NO.	NUMBER OF TREES	WEIGHT FACTOR PER TREE	INITIAL VIABLE EGGS PHASE I	PROPORTION OF TREES BY PERCENT REDUCTION IN CROWN HEIGHT 0.0	5.0	17.5	37.5	70.0	GROWTH IN SURVIVING TREES WITH NO TOP KILL PERCENT OF NOMINAL DIAMETER	HEIGHT	DIAMETER GROWTH IN TREES WITH TOP KILL PERCENT OF NOMINAL
1	1.0	1.0	.10	.0341	.0123	.0027	.0038	.0018	98.08	98.08	98.08
2	1.0	1.0	.50	.0341	.0123	.0027	.0038	.0018	90.39	90.39	90.39
3	1.0	1.0	1.00	.0341	.0123	.0027	.0038	.0018	80.78	80.78	80.78
4	1.0	1.0	2.00	.0341	.0123	.0027	.0038	.0018	59.68	59.68	59.68
5	1.0	1.0	3.00	.0341	.0123	.0027	.0038	.0018	46.68	46.68	46.68
6	1.0	1.0	3.50	.0341	.0123	.0027	.0038	.0018	53.49	53.49	53.49
7	1.0	1.0	4.00	.0341	.0123	.0027	.0038	.0018	54.50	54.50	54.50
8	1.0	1.0	4.50	.0341	.0123	.0027	.0038	.0018	59.46	59.46	59.46
9	1.0	1.0	5.00	.0341	.0123	.0027	.0038	.0018	59.14	59.14	59.14
10	1.0	1.0	6.00	.0341	.0123	.0027	.0038	.0018	56.33	56.33	56.33
11	1.0	1.0	8.00	.0341	.0123	.0027	.0038	.0018	36.17	36.17	36.17
12	1.0	1.0	10.00	.0877	.0293	.0053	.0019	.0005	28.38	28.38	28.38

TABLE 2. 2: OUTBREAK DEFOLIATION SUMMARY AND THE EXPECTED MORTALITY AND GROWTH REDUCTION 23:31:45 08/18/77

FOR THE DOUGLAS-FIR 30.000 / 70.000 TREE CLASSES

TREE CLASS NO.	NUMBER OF TREES	WEIGHT FACTOR PER TREE	INITIAL VIABLE EGGS PHASE I	MODEL BRANCH: PERCENT DEFOLIATION BY PHASE I	II	III	IV	PERCENT OF TREE TOTALLY DEFOLIATED	PROPORTION OF TREES RECEIVING: DIRECT MORTALITY	SECONDARY MORTALITY	TOP KILL	ONLY GROWTH REDUCTION
13	1.0	1.0	.100	.119	.498	2.745	.600	.000	0	.1272	.1158	.7570
14	1.0	1.0	.500	.596	4.490	13.723	3.002	.000	0	.1272	.1158	.7570
15	1.0	1.0	1.000	1.192	8.990	27.446	6.005	.002	0	.1272	.1158	.7570
16	1.0	1.0	2.000	2.383	17.959	65.568	48.047	9.203	0	.1272	.1158	.7570
17	1.0	1.0	3.000	3.575	26.938	73.009	56.135	35.045	.0090	.1010	.4163	.4736
18	1.0	1.0	3.500	4.171	32.289	80.135	64.336	72.169	.0280	.1075	.4820	.3825
19	1.0	1.0	4.000	4.767	39.247	86.642	71.664	90.667	.1730	.1999	.2888	.3383
20	1.0	1.0	4.500	5.363	45.601	94.962	81.156	96.959	.4770	.1144	.2005	.2081
21	1.0	1.0	5.000	5.959	52.094	100.000	89.484	100.000	.9230	.0168	.0295	.0306
22	1.0	1.0	6.000	7.150	65.053	80.590	63.133	74.087	.0280	.1075	.4820	.3825
23	1.0	1.0	8.000	9.534	90.280	91.553	75.288	95.573	.4770	.1144	.2005	.2081
24	1.0	1.0	10.000	11.917	98.207	100.000	86.800	100.000	.9230	.0168	.0295	.0306

TREE CLASS NO.	NUMBER OF TREES	WEIGHT FACTOR PER TREE	INITIAL VIABLE EGGS PHASE I	PROPORTION OF TREES BY PERCENT REDUCTION IN CROWN HEIGHT 0.0	5.0	17.5	37.5	70.0	GROWTH IN SURVIVING TREES WITH NO TOP KILL PERCENT OF NOMINAL DIAMETER	HEIGHT	DIAMETER GROWTH IN TREES WITH TOP KILL PERCENT OF NOMINAL
13	1.0	1.0	.10	.0694	.0464	0	0	0	97.26	97.26	97.26
14	1.0	1.0	.50	.0694	.0464	0	0	0	86.28	86.28	86.28
15	1.0	1.0	1.00	.0694	.0464	0	0	0	72.55	72.55	72.55
16	1.0	1.0	2.00	.0694	.0464	0	0	0	34.43	34.43	34.43
17	1.0	1.0	3.00	.1800	.2125	0	.0238	0	26.99	26.99	26.99
18	1.0	1.0	3.50	.2376	.1606	0	.0838	0	19.86	19.86	19.86
19	1.0	1.0	4.00	.1376	.0599	0	.0775	.0138	13.36	13.36	13.36
20	1.0	1.0	4.50	.1532	.0384	0	0	.0089	5.04	5.04	5.04
21	1.0	1.0	5.00	.0226	.0057	0	0	.0013	0	0	0
22	1.0	1.0	6.00	.2376	.1606	0	.0838	0	19.41	19.41	19.41
23	1.0	1.0	8.00	.1532	.0384	0	0	.0089	8.45	8.45	8.45
24	1.0	1.0	10.00	.0226	.0057	0	0	.0013	0	0	0

TABLE 3: PARAMETERS FOR AN OUTBREAK: MORTALITY, FOLIAGE DESTRUCTION, AND OTHER. 23:01:52 08/18/77
HOST TREE, STAND, PHASE, OR INSTAR SPECIFIC.

DESCRIPTION	PHASE	SPECIES	INSTAR 1	2	3	4	5	6	PUPAE MORTALITY	OVERWINTER MORTALITY	EGG MASS SIZE
DAILY MORTALITY RATE											
BACKGROUND	I,II,III,IV	DF,GF	.020	.020	.020	.020	.020	.020			
DISEASE	I	DF,GF	0	0	0	0	0	0			
	II	DF,GF	0	0	0	0	.001	.001			
	III	DF,GF	.002	.003	.006	.013	.035	.028			
	IV	DF,GF	.025	.028	.031	.034	.035	.035			
PARASITE/PREDATOR	I	DF,GF	0	0	0	0	0	0			
	II	DF,GF	0	0	0	0	.001	.001			
	III	DF,GF	.001	.002	.003	.010	.016	.042			
	IV	DF,GF	.005	.006	.007	.021	.033	.056			
STRESS	I,II,III,IV	DF	1.000	.750	.100	0	0	0			
	I,II,III,IV	GF	1.000	.800	.500	.100	0	0			
OCCASION MORTALITY RATE											
PUPAE	I	DF,GF							.500		
	II	DF,GF							.620		
	III	DF,GF							.750		
	IV	DF,GF							.800		
OVERWINTER	I - II	DF,GF								.500	
	II - III	DF,GF								.600	
	III - IV	DF,GF								.850	
	IV-	DF,GF								.900	
NOMINAL EGG MASS SIZE	I	DF,GF									200.0
	II	DF,GF									200.0
	III	DF,GF									150.0
	IV	DF,GF									150.0
DESTRUCTION/CONSUMPTION RATIOS											
NEW FOLIAGE	I,II,III	DF,GF	5.400	6.250	6.250	2.710	2.270	2.000			
OLD FOLIAGE	I,II,III	DF,GF	5.400	6.250	6.250	3.690	3.290	3.000			
INDIVIDUAL BIOMASS GROWTH RATE	I,II,III	DF,GF	.1147	.1147	.1147	.0886	.0625	.0625			

PHASE SPECIFIC MEAN EGG DENSITIES: I= 59.015 II=268.836 III= 19.538 IV= .525

REDISTRIBUTION COEFFICIENT FOR THE OUTBREAK: 0

TABLE 4: DETAIL RUN INFORMATION, PAGE 1

FOURTH INSTAR LARVAE — FOR GRAND FIR 35.00% NEW FOLIAGE

TREE CLASS	I	II	III	IV
1.	.055	.406	1.487	.103
2.	.273	2.029	7.436	.514
3.	.545	4.058	14.871	1.027
4.	1.091	8.116	29.742	1.808
5.	1.636	12.173	44.614	1.076
6.	1.909	14.202	26.025	.432
7.	2.182	16.231	14.871	.244
8.	2.455	18.260	4.183	.066
9.	2.727	20.289	2.324	.036
10.	3.273	24.347	.669	.010
11.	4.364	32.462	.195	.003
12.	5.455	40.578	.092	.001

THIRD INSTAR LARVAE — FOR GRAND FIR 35.00% NEW FOLIAGE

TREE CLASS	I	II	III	IV
1.	.067	.497	1.992	.185
2.	.334	2.483	9.960	.924
3.	.668	4.966	19.919	1.848
4.	1.335	9.932	39.838	3.252
5.	2.003	14.899	59.757	1.935
6.	2.337	17.382	69.717	.778
7.	2.670	19.865	79.677	.438
8.	3.004	22.348	89.636	.120
9.	3.338	24.831	99.596	.065
10.	4.006	29.797	114.734	.018
11.	5.341	39.730	133.057	.005
12.	6.676	49.662	125.849	.002

SIXTH INSTAR LARVAE — FOR GRAND FIR 35.00% NEW FOLIAGE

TREE CLASS	I	II	III	IV
1.	.018	.133	.235	.010
2.	.091	.664	1.174	.049
3.	.182	1.328	2.347	.098
4.	.364	2.655	4.695	.173
5.	.546	3.983	3.368	.103
6.	.637	4.647	1.432	.041
7.	.728	5.311	.918	.023
8.	.819	5.974	.230	.006
9.	.910	6.638	.129	.003
10.	1.093	7.966	.037	.001
11.	1.457	10.621	.011	.000
12.	1.821	10.754	.005	.000

FOURTH INSTAR LARVAE — FOR DOUGLAS FIR 30.00% NEW FOLIAGE

TREE CLASS	I	II	III	IV
13.	.055	.406	1.487	.103
14.	.273	2.029	7.436	.514
15.	.545	4.058	14.871	1.027
16.	1.091	8.116	29.742	1.438
17.	1.636	12.173	26.344	1.183
18.	1.909	14.202	26.831	1.186
19.	2.182	16.231	25.322	1.102
20.	2.455	18.260	24.774	1.061
21.	2.727	20.289	23.910	.481
22.	3.273	24.347	6.067	.247
23.	4.364	32.462	.029	.001
24.	5.455	32.868	.028	0

THIRD INSTAR LARVAE — FOR DOUGLAS FIR 30.00% NEW FOLIAGE

TREE CLASS	I	II	III	IV
13.	.067	.497	1.992	.185
14.	.334	2.483	9.960	.924
15.	.668	4.966	19.919	1.848
16.	1.335	9.932	39.838	2.587
17.	2.003	14.899	59.757	2.127
18.	2.337	17.382	67.626	2.133
19.	2.670	19.865	70.912	1.982
20.	3.004	22.348	77.097	1.908
21.	3.338	24.831	82.665	.865
22.	4.006	29.797	23.305	.445
23.	5.341	39.730	.110	.002
24.	6.676	49.662	.107	0

SIXTH INSTAR LARVAE — FOR DOUGLAS FIR 30.00% NEW FOLIAGE

TREE CLASS	I	II	III	IV
13.	.018	.133	.235	.010
14.	.091	.664	1.174	.049
15.	.182	1.328	2.347	.098
16.	.364	2.655	4.695	.138
17.	.546	3.983	4.158	.113
18.	.637	4.647	4.235	.113
19.	.728	5.311	3.997	.105
20.	.819	5.974	3.911	.101
21.	.910	6.638	3.774	.046
22.	1.093	7.966	.953	.024
23.	1.457	10.621	.005	.000
24.	1.821	10.754	.004	0

FALL PUPAE — FOR GRAND FIR 35.00% NEW FOLIAGE

TREE CLASS	I	II	III	IV
1.	.015	.106	.094	.003
2.	.074	.532	.470	.016
3.	.149	1.063	.940	.032
4.	.298	2.127	1.880	.056
5.	.446	3.190	1.349	.033
6.	.521	3.722	.574	.013
7.	.595	4.253	.328	.007
8.	.669	4.785	.092	.002
9.	.744	5.317	.051	.001
10.	.893	6.380	.015	.000
11.	1.190	8.506	.004	.000
12.	1.488	8.613	.002	.000

FALL PUPAE — FOR DOUGLAS FIR 30.00% NEW FOLIAGE

TREE CLASS	I	II	III	IV
13.	.015	.106	.094	.003
14.	.074	.532	.470	.016
15.	.149	1.063	.940	.032
16.	.298	2.127	1.880	.044
17.	.446	3.190	1.665	.036
18.	.521	3.722	1.696	.036
19.	.595	4.253	1.601	.034
20.	.669	4.785	1.566	.033
21.	.744	5.317	1.511	.015
22.	.893	6.380	.384	.008
23.	1.190	8.506	.002	.000
24.	1.488	8.613	.002	0

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GENERAL TECHNICAL REPORT PNW-90
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METRIC AND ENGLISH EQUIVALENTS

degrees Celsius	=	5/9 (degrees Fahrenheit minus 32)
1 hectare	=	2.47 acres
1 kilogram	=	0.45 pound
1 kilogram per hectare	=	0.89 pound per acre
1 kilometer	=	0.62 mile
1 liter	=	0.26 gallon
1 meter	=	3.28 feet

General Technical Report PNW-90
1979

ECOLOGICAL EFFECTS OF THE WICKERSHAM DOME FIRE NEAR FAIRBANKS, ALASKA

Technical Editors

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ABSTRACT

The Wickersham Dome fire occurred in late June 1971 and burned over 6 300 hectares of predominantly black spruce forest land. Shortly after the fire was controlled, studies of the effects of the fire on various components of the biotic community were undertaken. Results reported here are mainly for the first 3 years after the fire.

KEYWORDS: Fire effects, fire (-hydrology, soil properties (chemical), succession, fire (-regeneration, black spruce, *Picea mariana*, quaking aspen (*Populus tremuloides*), Alaska (Wickersham Dome).

HIGHLIGHTS

Examination of soil after the fire disclosed that moist, lower layers of the forest floor had minimized the impact of the fire on the soil. Burning reduced the thickness of the forest floor layer an average of 10.3 centimeters in heavily burned areas and 5.7 centimeters in lightly burned areas in a study location where the thickness averaged 28.7 centimeters in unburned areas. Burning did not have a measurable effect on the chemical properties of the underlying mineral soil. The reduction of forest floor thickness and the blackened surface resulted in higher soil temperatures. These higher temperatures caused a substantial retreat of the permafrost layer in burned areas. Depth to permafrost averaged 84 centimeters for burned areas and 47 centimeters for the unburned control 3 years after the fire.

Development of vegetation after the fire was closely tied to severity of the fire. On one lightly burned black spruce site, live ground vegetation cover still totaled 40 percent after the fire and included considerable amounts of mosses and *Cladonia* lichens. Vegetative cover at this location had increased to 70 percent 3 years after the fire. In contrast, recovery of vegetation in heavily burned black spruce stands was much slower. No mosses or lichens survived the fire, and most early cover was contributed by such herbaceous species as horsetail (*Equisetum sylvaticum*) and fireweed (*Epilobium angustifolium*). Few invading species appeared after the fire; most postfire cover was contributed by residual species which reproduced vegetatively. Biomass production was extremely variable over the burned area and, at the end of the 3d year, ranged from 33 grams per square meter in a heavily burned black spruce stand to 804 grams per square meter (mostly aspen sprouts) in a heavily burned aspen stand. Studies of leaves and needles in litterbags indicated that rates of decomposition were the same in burned and unburned stands. The 1st year after the fire, black spruce seed fall in the burned plots was almost four times as great as that in the unburned control. The germination capacity of black spruce seed was low in heavily burned areas and tended to decrease with time. On burned plots, only 1 percent of germinable seeds actually developed into established seedlings.

Studies of animals after the fire focused on arthropods, microtine rodents, and snowshoe hares (*Lepus americanus*). Numbers of spiders, Collembola, mites, Coleoptera, and other arthropods were higher in the burned area than in the unburned control. Numbers of northern red-backed voles (*Clethrionomys rutilus*) were substantially reduced after the fire, and the voles did not overwinter in the burned area until 3 years after the fire. The tundra vole (*Microtus oeconomus*), although rare in unburned black spruce stands, also established a resident population in the burned area 3 years after the fire. Because snowshoe hares were at a very high population level, they consumed large quantities of willow sprouts and charred bark during the fall and winter after the fire. Hare population levels stayed high until 1974, when they dropped precipitously. During the study period, the snowshoe hare population varied from a high of six hares per hectare in the fall of 1971 to a low of 0.12 hare per hectare in the spring of 1975.

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INTRODUCTION[1]

In interior Alaska, fire is an extremely important environmental factor. The varied array of forest communities--with paper birch (*Betula papyrifera* Marsh.), aspen (*Populus tremuloides* Michx.), black spruce (*Picea mariana* (Mill.) B.S.P.), and white spruce (*Picea glauca* (Moench) Voss) as principal tree components--displays patterns over the landscape which, in almost every case, can be directly traced to the distribution of past fires. Also, as a result of repeated wildfires, stands of trees older than 170 years are rare, except on islands in major rivers, throughout most of the Alaska interior. Wildfire statistics indicate that over the past 30 years about 400 000 ha a year were burned (Barney 1971).

Early interest in Alaska wildfires concentrated mainly on investigating means of improving fire control technology. Beginning about 1970, however, increasing numbers of individuals and Alaska groups began to propose that wildfires might be beneficial in some cases. Some suggested that since wildfires started by lightning are a normal part of the taiga environment, areas should be designated where wildfires are allowed to burn and natural processes permitted to continue as in the past. Proponents argued that such a policy would reduce fire control costs, lessen environmental degradation caused by fire suppression activities, and increase the acreage of seral plant communities important to herbivores, such as moose. Choice of optimum fire management strategies for interior Alaska cannot be made, however, without sufficient quantitative information on the effects of wildfires on taiga ecosystems. Because this necessary information is not available, scientists at the Institute of Northern Forestry are attempting to gain a better understanding of the role of fire in the distribution, structure, and function of taiga ecosystems.

An important part of this effort has been intensive study of an area on Wickersham Dome burned over by a 1971 wildfire. A multidisciplinary study was initiated soon after the fire was controlled, in an attempt to assess the impact of the fire on biotic communities and their environments. Scientists representing several disciplines directed their talents to the study of as many abiotic and biotic factors as possible. The most intensive portion of this study extended through 1973, although certain portions of the study are still continuing.

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[1]This section was prepared by C. T. Dyrness, Supervisory Soil Scientist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

DESCRIPTION OF STUDY AREA[2]

The Wickersham Dome research area is located about 50 km northwest of Fairbanks, adjacent to the Elliott Highway (fig. 1). It is situated within the Yukon-Tanana Uplands physiographic province, an area of relatively gentle relief with rounded ridges oriented in a northeast-southwest direction. Elevations range from 210 m at the lowest level along Washington Creek to 980 m at the summit of Wickersham Dome. The area lies within the boundaries of the Pipeline Corridor Reserve designated by the Bureau of Land Management, U.S. Department of the Interior.

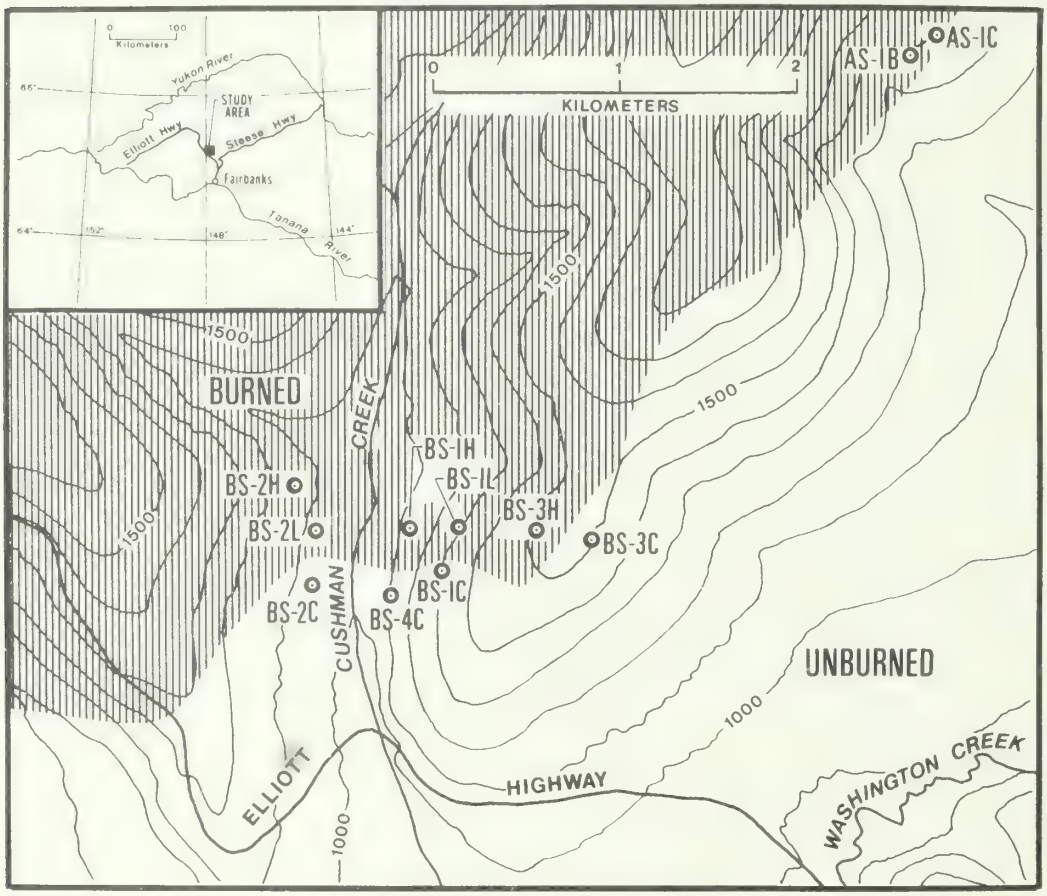


Figure 1.--Location of Wickersham Dome fire and sampled stands.

[2]Description prepared by C. T. Dyrness, Supervisory Soil Scientist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

Geologically, the area is characterized by Precambrian schist and gneiss bedrock which has not been modified by glaciation. Except at highest elevations, bedrock is mantled by a layer of wind-deposited loess. The study area lies within the zone of discontinuous permafrost. Ridgetops and upper south slopes tend to be free of permafrost. In other locations, however, permafrost is generally about 40 to 50 cm below the surface. Mineral soils are silt loam in texture and are mantled by organic materials (mostly mosses and litter) approximately 20 to 50 cm thick.

Before the 1971 wildfire, the area was mainly covered with black spruce stands, ranging in age from 50 to 125 years, depending on fire history. Stands were open, dominated by slow-growing black spruce 6-10 m in height and 8-12 cm in diameter, and interspersed with occasional paper birch and scattered large willow (mostly *Salix scouleriana* Barratt) and alder (*Alnus crispa* (Ait.) Pursh) shrubs. The most conspicuous vascular plants in the understory were low shrubs, such as Labrador-tea (*Ledum groenlandicum* Oeder), bog blueberry (*Vaccinium uliginosum* L.), mountain-cranberry (*Vaccinium vitis-idaea* L.), and prickly rose (*Rosa acicularis* Lindl.). A nearly continuous moss cover was present, made up of feather mosses, with some *Sphagnum*. Lichens were also conspicuous components of the ground cover, primarily *Cladonia* and *Peltigera* species. Stands of quaking aspen occurred on some slopes and were characterized by a striking decrease in moss cover in the understory.

The fire, ignited by lightning on June 24, 1971, started near Wickersham Dome. Bureau of Land Management personnel made an all-out effort to control the fire--775 people, 29 bulldozers, 6 pumps, 4 tankers, and 4 helicopters--but the fire proved difficult to control because of low fuel moisture and generally brisk breezes. The fire burned in a southwesterly direction and was finally stopped on June 30, but only after 242 000 liters of retardant had been aerially dropped. General outline of the burned area is shown in figure 1.

Burned area totaled 6 313 ha, of which 5 100 ha were Federal and 1 213 ha were State or privately owned. Expenditures for control totaled $1,099,479; damages to timber, recreation, soil, grazing, and wildlife resources were estimated at $655,200 (Noste and Davis 1975).

Weather conditions at the time of ignition on June 24 were conducive to fast rates of fire spread, contributing to the failure of initial attack. The maximum reported temperature of 30°C, combined with a calculated 2.5-percent fine fuel moisture and 6 m/s wind, yields a spread index of 70 (table 1)--a value exceeded less than 1 percent of the time, based on Fairbanks records (Barney 1967). Conditions on June 25 and 26 had a similarly high potential for fire, except the wind was much lower--only 3 m/s. The spread index was 43 and 42 on June 25 and 26; these are exceeded only about 20 percent of the time. On June 27, windspeed increased again, yielding a spread index of 58, a value exceeded less than 5 percent of the time. By this time the head of the fire had reached a ridgetop between Washington Creek and

Table 1--Weather conditions at Fairbanks during the Wickersham Dome fire, 1971

June	Maximum temperature	Relative humidity	Fine fuel moisture	Windspeed	Direction	Spread index	Buildup index
	°F	- - -Percent- - -		Miles per hour			
24	86	15	2.5	14	N	70	128
25	85	17	3.0	7	N	43	133
26	84	19	3.5	7	NE	42	138
27	84	20	3.5	12	N	58	143
28	75	24	5.0	13	NE	60	146
29	62	32	6.5	14	E	54	149
30	58	52	11.0	6	NE	23	150

the Chatanika River, and the rates of spread decreased substantially. The days on which the fire burned, being so near the summer solstice, had very short nights with little time for recovery of moisture in the fine fuels.

The buildup index, a measure of moisture content in the heavier fuels, is a relative indicator of the potential intensity of the fire. Historically, values of 128 are exceeded about 3 percent of the time during the fire season in the fire area. Burning conditions, as indicated by the spread and buildup indexes, were quite severe at the time of ignition and during the major part of the time the fire was spreading.

Bulldozers constructed about 113 km of fireline which averaged 12 m in width. Because much of the area is underlain by permafrost, erosion was rapid when the insulating mat of organic materials was removed. Soon after the fire, it was estimated that at least 75 percent of dozer-constructed firelines needed rehabilitation to prevent or slow erosion. By July 4, 1971, melting of exposed permafrost had proceeded to such an extent that it was causing considerable erosion and siltation of Washington Creek. Therefore, an extensive program of tractor-construction of water bars and diversion ditches on firelines was begun immediately. In addition, during the following April (1972), firebreaks were aerially sown with grass and fertilized. The seed mixture consisted of Manchar smooth brome (37.5 percent), creeping red fescue (37.5 percent), and Rodney oats (25 percent), applied at a a rate of 45 kg/ha. Also aerially applied were 336 kg/ha of pelleted 10-20-20 fertilizer.

SELECTION OF STUDY PLOTS[3]

In August 1971, we selected sites for intensive study of the effects of fire in black spruce stands. We intended to secure three sets of plots, each containing three plots--an unburned stand (control--called the unburned control), a lightly burned stand, and a heavily burned stand; however, for one set of plots, only a heavily burned stand was available besides the unburned control.

Criteria used for evaluation of the intensity of the burn were:

> Lightly burned--less than 50 percent of the ground surface blackened; lesser vegetation not consumed; branchlets present on trees and crowns scorched but not consumed.
>
> Heavily burned--more than 90-95 percent of the area blackened; lesser vegetation and tree crowns consumed.

We did not attempt to evaluate stands with 50-90 percent of the area blackened.

The three sets of plots selected were along a generally east-west transect across the burned area. All were in areas of black spruce. Plot set 1 was located between 335 and 396 m in elevation. This set of plots was on a west-facing slope with a gradient of 12-20 percent and consisted of an unburned control plus a lightly burned and a heavily burned stand. Plot set 2, consisting of an unburned control and a lightly burned and a heavily burned stand, was located at approximately 335-m elevation on a gentle, east-facing slope. Plot set 3 was located at an elevation of approximately 468 m on the nearly flat crest of a ridge; slopes, having a generally western aspect, were 0 to 5 percent. Plot set 3 consisted of only two stands, an unburned control and a heavily burned stand. Examples of the three conditions are shown in figures 2, 3, and 4.

During the summer of 1972, three additional plots were established. A set of two plots (plot set 4)--one heavily burned (fig. 5) and the other an unburned control--was located in an area of aspen at an elevation of approximately 510 m at a midslope position; slopes were 13-15 percent, and aspect was dominantly south. In addition, another unburned stand, situated on a lower portion of the slope (at an elevation of 335 m), was added to plot set 1 as a control for the nearby heavily burned plot. Characteristics of all the plots are summarized in table 2.

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[3]This section was prepared by C. T. Dyrness, Supervisory Soil Scientist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.



Figure 2.--General view of unburned black spruce stand.



Figure 3.--Lightly burned stand (BS-1L), showing typical ground cover remaining after the fire.



Figure 4.--General condition of heavily burned stands is shown here by stand BS-3H. Light color in background is unburned but killed Sphagnum moss mound.



Figure 5.--View of burned aspen stand in August 1972 (AS-1B) shows development of aspen sucker shoots. Note how snowshoe hares removed the charred bark during the 1971-72 winter.

Table 2--Physical description and burn intensity of 11 stands after the Wickersham Dome fire

Plot set	Stand	Slope	Aspect	Elevation	Slope position	Burn intensity	Year of establishment
		Percent		Meters			
1	BS-1C	20	West	396	Middle	Control	1971
1	BS-1L	15	West	396	Middle	Light	1971
1A	BS-1H	12	West	335	Lower	Heavy	1971
1A	BS-4C	12	Southwest	335	Lower	Control	1972
2	BS-2C	5	Southeast	335	Lower	Control	1971
2	BS-2L	10	East	335	Lower	Light	1971
2	BS-2H	12	East	335	Lower	Heavy	1971
3	BS-3C	0	Level	468	Ridgetop	Control	1971
3	BS-3H	5	West	468	Ridgetop	Heavy	1971
4	AS-1C	13	Southwest	518	Middle	Control	1972
4	AS-1B	15	South	503	Middle	Heavy	1972

ABIOTIC FACTORS

The Soil

General description of soils in the study area[4]

Soils in the Wickersham Dome area are formed in a layer of wind-deposited silty materials (loess) over weathered mica schist bedrock of the Birch Creek formation. The loess mantle varies in thickness from a few centimeters on steep slopes and ridgetops to over a meter on lower slopes and valley bottoms. Since this is an area of discontinuous permafrost, soils frequently lack permafrost on ridgetops and south-facing slopes, but shallow permafrost is present in soils on north-facing slopes and valley bottoms. Soils with a shallow permafrost table are marked by deep (up to 50-cm), overlying layers of moss and litter and a continuously wet profile throughout the growing season.

During the summer of 1974, C. E. Furbush and D. B. Schoephorster, soil scientists with the U.S.D.A. Soil Conservation Service, mapped the soils over most of the fire area. They identified five soil series in the area--Ester, Fairplay, Gilmore, Goldstream, and Saulich. The Ester, Fairplay, and Saulich series occur in the plot areas and therefore we will describe them in some detail.

[4]Description prepared by C. T. Dyrness, Supervisory Soil Scientist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

The Gilmore series is restricted to upper slopes and ridgetops and consists of well-drained, permafrost-free soils formed in a shallow loess mantle over gravelly silt loam derived from the underlying weathered schist. Soils classified in the Goldstream series are poorly drained, silty soils that occur in valley bottoms. These soils typically have a shallow permafrost table and are therefore wet throughout the summer.

According to results of the soil survey, plots making up plot set 1 are situated on two soil series--the Ester and the Saulich. Fortunately, each soil has both a burned stand and an unburned control.

One unburned control and a lightly burned stand are in an area of Ester silt loam, a poorly drained soil that occurs on north-facing slopes. These soils are generally shallow to both permafrost and bedrock (silt mantle is generally less than 50 cm thick). Ester soils typically have a thick moss and litter surface layer over mottled dark grayish-brown silt loam or gravelly silt loam; amounts of gravel increase with depth. The permafrost table is generally within 25 cm of the surface of the mineral soil, and the soil above the frost line is invariably wet. Where bedrock is shallow or the surface organic layer is thin, permafrost may be lacking above the rock.

The heavily burned stand and the unburned control in plot set 1 are situated on Saulich silt loam soils which, in many respects, resemble Ester soils but are formed in deeper loess deposits on lower slopes. Saulich soils are poorly drained, have shallow permafrost layers, and are generally very moist to wet. They are formed in silt loam deposits more than 75 cm thick. A typical Saulich profile has a moss-litter layer 25-30 cm thick, underlain by 10 cm of very thick, very dark grayish-brown silt loam A1 horizon, over a frozen B1 horizon made up of mottled olive gray silt loam.

All three stands in plot set 2 are also located on Saulich silt loam soils.

Plot set 3, consisting of an unburned control and a heavily burned stand situated on a ridgetop, is in an area of soil classed as Fairplay silt loam. These soils are moderately well drained to somewhat poorly drained and are characteristic of upper slopes and ridgetops. Permafrost, if present, is at substantial depths (at least 150 cm). Fairplay soils typically have a relatively thin organic layer over mottled dark grayish-brown gravelly silt loam which varies from 50 to 100 cm in thickness over schist bedrock. Gravel content, made up of angular schist fragments, ranges from very little to 35 percent by volume.

Unfortunately, the two plots in the area of aspen were not within the soil survey area. Therefore, the soils in that area have not been described and classified.

Soil taxonomic units at the suborder level for the Saulich and Ester series is Histic Pergelic Cryaquept and for Fairplay, Aquic Cryorthent.

Effects of burning on forest floor characteristics[5]

One of the outstanding characteristics of taiga soils is the thick organic layer which generally overlies the mineral soil. These layers, mainly comprised of organic matter produced by mosses and lichens, as well as vascular plant litter, are especially thick under black spruce stands, where they may reach depths of 50 cm or more. The degree to which these layers are consumed by fire controls, to a large extent, characteristics of the postfire community. Site factors greatly influenced by depth of burning in the organic layer include soil temperature and thickness of the active layer, levels of available soil nutrients and subsequent rates of mineralization, and condition of the seed bed during initial stages of secondary succession. The amount of mineral soil exposed as a result of burning is an especially important consideration because it offers the most suitable seed bed for germination of all species of Alaska taiga trees and most of the shrubs (Viereck 1973).

In the Wickersham Dome study area, observations of forest floor characteristics in both burned and unburned stands were conducted during the fall of 1971. At 20 points within each of eight stands, a 15-cm-diameter core of the forest floor was removed, including organic material as well as a portion of the mineral soil. After the cores were separated into mineral and organic components, the organic portion was taken to the laboratory, ovendried, and weighed. The depth of the organic layer was measured on the side of the hole after the core was removed. Data for each plot were summarized by total thickness, weight, and bulk density of the organic layer.

The data were analyzed for differences between location and intensity of burn. The statistics are intended for descriptive purposes for an understanding of the magnitude of the observed effects rather than conclusive inferences from the data. The only statistically significant difference in the thickness of the layer was between the heavily burned stand and the unburned control in plot set 1.

Examination of organic layer thicknesses (table 3) indicates that plot set 3, on the ridgetop, had a much thinner litter and moss layer; and less litter (1.0 cm) was removed by the fire. In plot set 2, comparisons of the burned stand with the unburned control indicate reductions of 3.35 cm in thickness of the forest floor in the heavily burned stand and 1.90 cm in the lightly burned stand. Stands in plot set 1 had the thickest organic layers, and more material was apparently consumed by the fire.

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[5]This section was prepared by N. V. Noste, Fire Scientist, and R. J. Barney, Fire Scientist, Forest Service, U.S. Department of Agriculture, Northern Forest Fire Laboratory, Missoula, Mont.; and K. P. Burnham, Biometrician, Fish and Wildlife Service, U.S. Department of the Interior, Western Energy and Land Use Team, Fort Collins, Colo.

Table 3--Thickness, ovendry weight, and bulk density of forest floor layers in 8 burned stands and unburned controls in the Wickersham Dome fire study area[1/]

Plot set, slope, and treatment	Total thickness		Weight		Bulk density	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
	- -Centimeters- -		- - -Grams- - -		Grams per cubic centimeter	
Plot set 1, west-facing slope of 12-20 percent:						
Unburned control	28.70	6.95	220.90	57.10	0.043	0.011
Lightly burned	23.00	6.71	224.10	66.64	.056	.020
Heavily burned	18.40	4.29	346.05	260.61	.104	.075
Plot set 2, very gentle, east-facing slope:						
Unburned control	21.45	3.77	290.25	81.73	.077	.028
Lightly burned	19.55	5.73	297.20	121.00	.093	.057
Heavily burned	18.10	3.46	287.35	126.36	.088	.041
Plot set 3, ridgetop:						
Unburned control	13.90	5.80	308.70	117.90	.136	.062
Heavily burned	12.95	4.38	249.60	94.85	.109	.039

[1/]Each value represents the mean of 20 measurements.

After the fire, the difference in thickness of the forest floor between the unburned control and the heavily burned stand was 10.30 cm; the difference between the lightly burned stand and control was 5.70 cm. Differences among all three treatments in plot set 1 were found to be statistically significant (table 3).

A statistically significant interaction exists between location and intensity. A pattern of consistently less reduction in forest floor thickness from the lower stands (plot set 1) toward the ridgetop can be recognized. More reduction of the organic layer progressing from the light to the heavy intensity burn may also contribute to the significant interaction.

Apparently because of the extreme variability in weight values, neither the light nor the heavy burns removed sufficient organic material to consistently show a significant weight loss; and there was no apparent difference in weight relative to burn intensity. The extreme variability in forest floor weights may have been at least partially caused by the difficulty encountered in obtaining a clean separation between organic and mineral soil. Because of this, the organic layer samples were contaminated by variable amounts of mineral soil particles.

In summary, it appears that the Wickersham Dome fire removed only relatively small portions of the forest floor material. Although comparisons of depths of organic layers in burned areas with those in the unburned controls consistently indicated reductions with burning, in two out of five instances these differences were not statistically significant. The greatest reduction in forest floor thickness occurred on plots having the thickest layers, and even here the heavily burned layer was almost two-thirds as thick as that in the unburned control.

Mineral soil characteristics following burning[6]

Most studies of fire and soil relationships have shown that burning may have significant effects on mineral soil properties--especially in intense fires, the fertility of the surface soil is often altered considerably. In temperate regions of the United States, changes resulting from burning generally indicate reduced quantities of organic matter, nitrogen, and in some instances, phosphorus, but significantly increased amounts of exchangeable cations, such as potassium, calcium, and magnesium, as well as an increase in soil pH (Dyrness 1963). Lutz (1956) in Alaska and Scotter (1971) in northern Canada, however, reported an increase not only in exchangeable calcium and potassium but also in nitrogen and phosphorus after fire. The increased amounts of nitrogen and phosphorus in the taiga probably represent a fire-generated release of these elements to the mineral soil from deep, overlying organic layers. In more temperate regions, forest floor layers are usually not as thick.

To determine possible effects of the Wickersham Dome fire on soil properties, we analyzed samples of mineral soil in the laboratory. These samples were collected in the fall of 1971 concurrently with the organic layer samples and consisted of cores 15 cm in diameter, which included the upper 15 cm of the mineral soil. In each of the 11 plots (9 in black spruce and 2 in aspen) 20 samples were collected; 4 from each plot were randomly selected for soil analysis. Laboratory determinations included particle size distribution; pH; cation exchange capacity; exchangeable potassium, calcium, and magnesium; available phosphorus; and total nitrogen.

Results of soil analyses are shown in table 4. For purposes of comparison, data are grouped by plot sets, and each set contains at least one unburned control plot as well as a nearby burned plot (table 2).

Close inspection of the results reveals a high degree of variation among the plots, especially in chemical properties (table 4). Because of this, it is impossible to discern any consistent differences in soil properties between the burned stands and unburned controls. There are several possible reasons for this lack of correlation. The first, and perhaps the most important, is the depth of mineral soil sampled (15 cm). Since the most pronounced effects of burning would be expected in the surface 2-3 cm of soil, the sampling procedure may have effectively masked differences at the surface of the mineral soil. In addition, inherent soil variability may be sufficient in this area to preclude the possibility

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[6]This section was prepared by N. V. Noste, Fire Scientist, and R. J. Barney, Fire Scientist, Forest Service, U.S. Department of Agriculture, Northern Forest Fire Laboratory, Missoula, Mont.; and C. T. Dyrness, Supervisory Soil Scientist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

Table 4--Results of analyses of samples of the 0- to 15-cm layer of mineral soil for 11 stands after the 1971 Wickersham Dome fire[1/]

Plot set and treatment	Sand	Silt	Clay	Textural class[2/]	pH	Cation exchange capacity	Exchangeable						Available P	Total N
							K		Ca		Mg			
	- - -Percent- - -					meq/100 g	p/m	meq/100 g	p/m	meq/100 g	p/m	meq/100 g	p/m	Percent
BLACK SPRUCE														
Set 1:														
Unburned control	18.85	67.95	13.20	Si.Lo.	4.12	41.24	0.980	0.25	7.417	1.85	1.865	0.77	1.5778	0.45041
Lightly burned	23.20	65.32	11.48	Si.Lo.	4.22	32.83	.853	.22	6.634	1.66	1.526	.63	1.6474	.38365
Unburned control[3/]	11.45	77.07	11.48	Si.Lo.	4.52	24.81	.830	.21	16.410	4.09	2.894	1.19	3.2133	.26790
Heavily burned	31.81	55.45	12.74	Si.Lo.	4.82	14.89	.596	.15	15.187	3.79	2.208	.91	2.7134	.16747
Set 2:														
Unburned control	7.13	81.21	11.66	Si.	5.09	34.59	.910	.23	31.078	7.75	3.150	1.30	2.6412	.28676
Lightly burned	19.33	73.63	7.04	Si.Lo.	4.66	19.78	.634	.16	11.956	2.98	2.762	1.14	2.7569	.18583
Heavily burned	9.33	79.35	11.32	Si.Lo.	4.93	31.18	1.054	.27	31.811	7.94	2.772	1.14	4.3714	.31804
Set 3:														
Unburned control	11.71	74.34	13.95	Si.Lo.	4.93	12.86	.956	.24	5.389	1.34	1.304	.54	3.4128	.06779
Heavily burned	11.45	74.59	13.96	Si.Lo.	4.73	21.68	1.226	.31	10.035	2.50	2.420	1.00	2.6072	.16791
ASPEN														
Set 4:														
Unburned control	24.34	63.56	12.10	Si.Lo.	3.84	29.17	1.361	.35	7.892	1.97	1.397	.57	12.7320	.31914
Heavily burned	14.08	71.67	14.25	Si.Lo.	4.00	22.26	1.807	.46	6.561	1.64	1.585	.65	15.9896	.20924

[1/] Each value represents the mean of 4 determinations.

[2/] Si.Lo. = silt loam; Si. = silt.

[3/] Plot added in 1972.

of successfully characterizing the effects of burning on the basis of such a comparatively small sample. If this is the case, measurements of samples collected from the same location before and after burning would be much more likely to reflect the actual effects of fire.

Although the effects of burning on the soil samples are not apparent, the data do reflect certain differences (table 4). Perhaps the most striking is the appreciably higher amounts of available phosphorus in soils under aspen. This is not surprising; it is well known that aspen litter contains much larger quantities of phosphorus than does spruce litter (Rodin and Bazilevich 1967). Other differences, apparently also a function of plot location, are noticeable. For example, soil from the unburned control on the ridgetop (plot set 3) has a considerably lower total nitrogen content and is also lowest in cation exchange capacity and exchangeable calcium and magnesium.

On the basis of these results, we recommend that mineral soil samples be collected in depth increments of 2-3 cm at many locations in future studies of fire effects. In addition, sampling should be done at intervals after the fire so the redistribution of mobilized elements by leaching or other processes can be followed.

Effect of burning on soil temperature[7]

One of the important changes taking place in the soil after fire is modification of temperatures. Because of the increase in surface absorption of solar heat, the reduced thickness of the organic layer, and the lack of surface vegetation, temperatures tend to be warmer in a burned soil than in an unburned soil.

To compare soil temperatures in the burned and unburned stands in plot set 3 (table 2), we installed a series of thermistors at the following depths: forest floor surface, 5 cm in the organic layer, organic-mineral soil interface, 10 cm below mineral soil surface, 20 cm below mineral soil surface, and 50 cm below mineral soil surface.

These temperatures were recorded once a week about noon throughout the year.

Graphs for soil temperatures at 5 cm in the organic layer and at the 10- and 50-cm depths in the mineral soil are shown in figures 6, 7, and 8.

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[7]This section was prepared by L. A. Viereck, Principal Plant Ecologist, and M. J. Foote, General Biologist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.



Figure 6.--Soil temperature at a depth of 5 cm in the organic layer at burned and unburned control sites during the 1st year after burning.

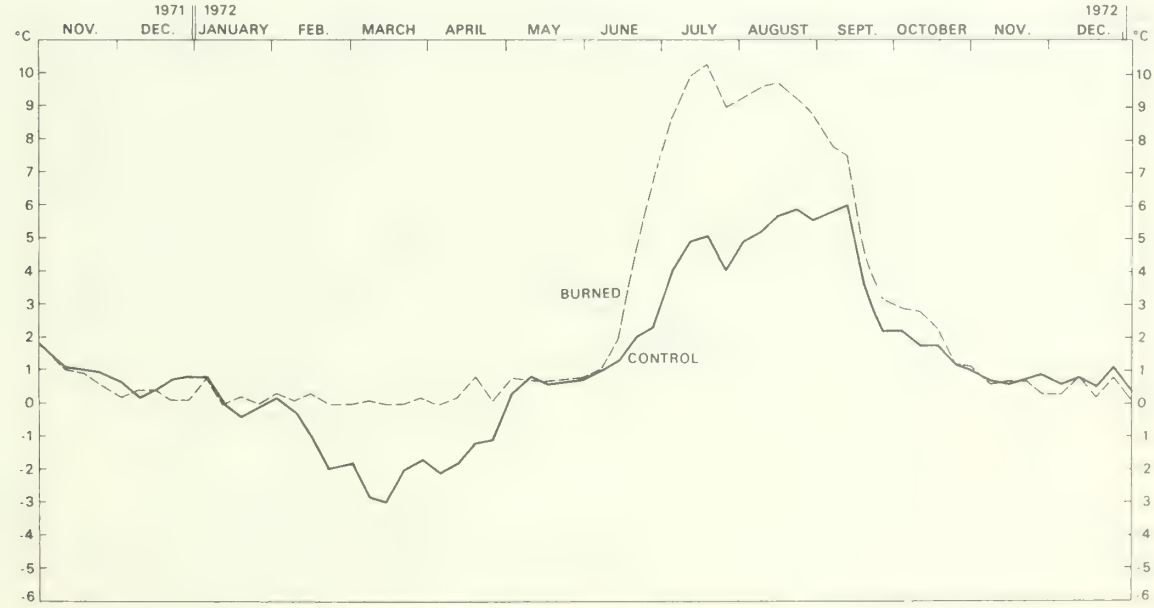


Figure 7.--Soil temperature at a depth of 10 cm in the mineral soil at burned and unburned control sites during the 1st year after burning.

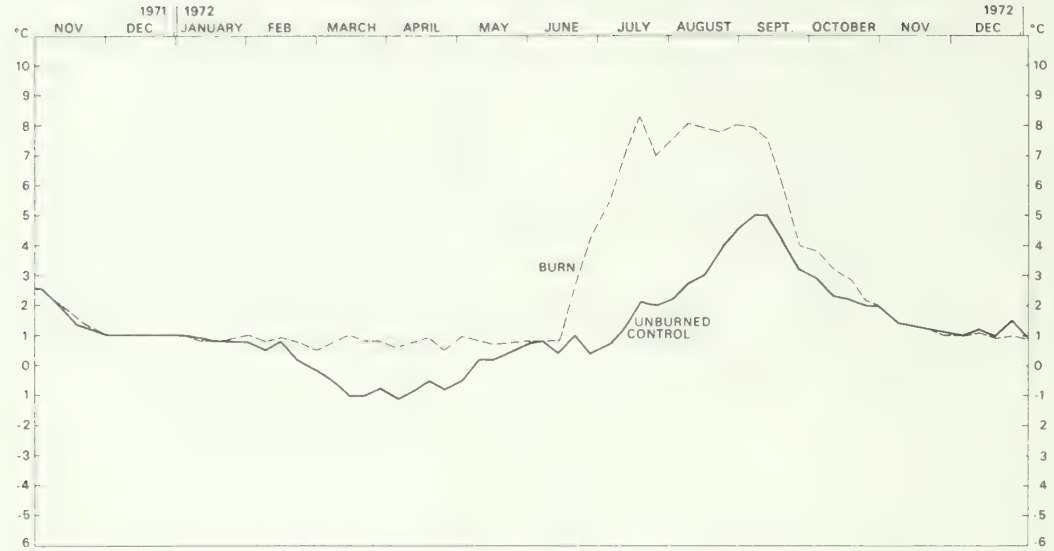


Figure 8.--Soil temperature at a depth of 50 cm in the mineral soil at burned and unburned control sites during the 1st year after burning.

For the 10-cm depth (fig. 7), temperatures during the fall of 1971, the same year as the fire, were similar in burned and unburned areas until the end of January. During February and until mid-March, temperatures continued to decline in the unburned stand until a low of -3°C was reached in mid-March. In the burned stand, temperatures remained close to 0°C until April 10. During May and early June, the temperatures at 10 cm in the mineral soil were similar. After the final melting of the overlying snow in mid-May to late May, there was a rapid rise in soil temperatures in the burned stand; a high of 10.5°C was reached on approximately July 20. The soil in the unburned control warmed much more slowly during the summer with a much greater timelag and did not reach its warmest point, 6°C, until September 13, long after the close of the active growing season and within a week of the first snowfall. During the cooling period in September and October, the rates were similar; but the burned stand remained warmer until the end of October, at which time the temperatures were once again about the same.

A comparison of the 10-cm soil temperature (fig. 7) with air temperature illustrates an interesting and well-documented timelag. Although the coldest air temperatures occurred the first 2 weeks in January, the soil temperatures at 10 cm did not reach the coldest point until 2 months later. Similarly, summer air temperatures were at a maximum in mid-June, but soil temperatures at 10 cm did not reach a maximum until July 20 in the burned area and the middle of September in the unburned control.

If the soil temperatures are compared with air temperatures, as snow melts we can see that, although air temperatures are well above the freezing point by mid-May, soil temperatures do not begin to rise above 0°C until all the snow is melted.

In the fall of 1972 the permanent snow cover came while soil temperatures were relatively warm. This may have resulted in the rapid cooling in the organic layer in mid-September. On the other hand, the snow cover seems to have insulated the soil from the effects of the cold period in late October.

Figures 6 and 8 show soil temperatures for the 5-cm depth in the organic layer and for the 50-cm depth in mineral soil. As would be expected, the litter layer shows a much wider fluctuation of temperatures. Some of the same patterns as occurred at the 10-cm depth in the mineral soil, however, are apparent. A surprising fact is that, during most of the summer soil temperature for the organic layer in the burned stand were 2^{o}-4^{o} higher than in the unburned control (fig. 6), but at the time of the highest temperature in July the temperature in the organic layer beneath living mosses in the unburned control was greater than that in the burned forest floor with a charred surface.

As expected, mineral soil temperatures at a depth of 50 cm showed less fluctuation and range than those at 10 cm or in the organic layer (fig. 8). Also, the timelag was longer, the minimum temperature occurred in April, and no warming occurred until after mid-June in the burned stand and mid-July in the unburned control.

Temperature-sensitive pellets were placed on the surface of the blackened, burned organic material on June 15, just after the hottest days of the summer. During the week of June 15-22, the temperature reached at least $59^{o}C$. During July, the highest surface temperatures were between $55^{o}C$ and $50^{o}C$; and by August they were between $48^{o}C$ and $55^{o}C$. Surface temperatures as high as those in June are considered lethal to tree seedlings.

Permafrost[8]

An important effect of wildfire in the taiga of Alaska is alteration of the thickness of the active layer (thawed soil above the permafrost layer). Few data are available for thickness of the active layer after fire in forest stands in Alaska, but the active layer generally is known to be thicker in successional stands after fire than it is in unburned black spruce forests. The actual heat produced by the fire is probably unimportant, as the organic layer seldom burns to the permafrost boundary. Brown (1965) stated, "A fire may burn trees, brush, and even the surface of the moss without altering the underlying permafrost." After a fire, however, the changes in the surface albedo and the removal of the vegetation and some of the organic mat result in warmer soils and deeper thawing. After a fire in the black spruce type at Inuvik, in Northwest Territories, Canada, Hegginbottom (1971) reported that by the summer after the fire, the thaw was 9 cm deeper in burned than in unburned

[8]This section was prepared by L. A. Viereck, Principal Plant Ecologist, and M. J. Foote, General Biologist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

stands. From eight permanent points on the Inuvik fire, Mackay (1970) reported an average increase of thaw of 24.1 cm (149 percent) by the end of the first summer after the fire and 24.8 cm (171 percent) by the end of the second summer. Cody (1964) reported that 3 years after a taiga fire in the Reindeer Grazing Reserve on the Mackenzie Delta, the permafrost had receded to a depth of 40 cm or more, and the recession of the ice had caused surface subsidence which resulted in a hummocky terrain.

At the end of the first summer after an August and September burn in eastern Alaska, Lotspeich et al. (1970) found no significant difference in thaw depth--both burned and unburned stands had thawed to approximately 70 cm. In an *Eriophorum* tussock tundra within the taiga of Alaska, Wein (1971) reported a 130- to 150-percent increase in the active layer in early summer after a fire the previous year, but only 115- to 120-percent difference by the time of maximum thaw in the fall. Brown et al. (1969) reported an increased thaw of 160 and 140 percent 4 years after a fire in a black spruce/*Eriophorum* tussock type in eastern Alaska. They also reported a 141- and 152-percent increase in thaw depth in a 1-year-old burn in an *Eriophorum* tussock type with scattered black spruce in central Alaska.

At the northern limit of forest vegetation in Russia, however, fire may result in a thickening of the active layer, followed in a few years by a rise in the permafrost upper surface. Kryuchkov (1968) reported that fire first caused a thawing of the upper permafrost layers with a resultant release of moisture, creating conditions which stimulated the growth of the *Eriophorum* cover. As a result of the insulating effects of the thicker vegetation mat, the active layer was only 40-45 cm thick a few years after the fire, whereas before the fire it had been 50-70 cm.

At Wickersham Dome we studied the annual freezing and thawing cycles and the depth to permafrost by three methods:

1. Weekly readings of soil temperature at two sites, one in a heavily burned stand and one in an unburned control at the ridge-top site (plot set 3).

2. Frost tubes filled with sand and a fluorescein dye (Rickard and Brown 1972) were installed in six stands, three burned stands and three unburned controls.

3. Probe lines were established so we could follow the recession of the frostline in burned stands, unburned controls, and the firelines; 10 probes were taken at each site and average depth to frozen soil was recorded.

We used the frost tubes to follow the freezing in the fall and winter, but the probe lines were better for following the thaw during the summer.

Because of the variation in depth to bedrock and depth to which frost tubes could be installed, general comparisons between all the burned stands and unburned controls were impossible. Instead, observations of permafrost were concentrated on three stands on organic soils near Cushman Creek: a heavily burned black spruce stand (BS-1H), its unburned control (BS-4C)--plot set 1A in table 2, and an adjacent heavily bulldozed fireline.

In the fall of the first summer after the fire, there was no significant difference between burned stands and unburned controls. Probing in four stands in the burn showed thaw to an average depth of 44 cm, whereas in the adjacent unburned controls the average thaw was to 47 cm.

Figure 9 shows the freeze-thaw cycle in a heavily burned stand and an unburned control for the 1st year after the fire. In the fall after the fire, there was no significant difference in the depth of the thaw (40 cm in the unburned control and 41 cm in the heavily burned stand). During the first winter after the burn, freezing occurred more rapidly in the unburned control than in the burned stand. The active layer was completely frozen by December 12 in the unburned control but not until January 15 in the burned stand.

The next summer, thawing was deeper in the burned stand than in the unburned control. Although the snow melted 2 weeks earlier in the burned stand than in the unburned, thawing was similar in both until June 7; after that, thawing was more rapid in the burned stand. Thawing to nearly the maximum depth of 63 cm had occurred by August 23 in the burned stand and to a maximum of 40 cm by September 6 in the unburned control. Thus, depth of thawing in the burned stand the first summer after the fire was 157 percent of that in the unburned control. Probing was also carried out in the fireline between the two stands. The rate of thaw during 1972 was more rapid in the fireline than in either the control or the heavily burned stand. Maximum depth of thaw in the fireline was 88 cm or approximately 200 percent of that in the unburned control.

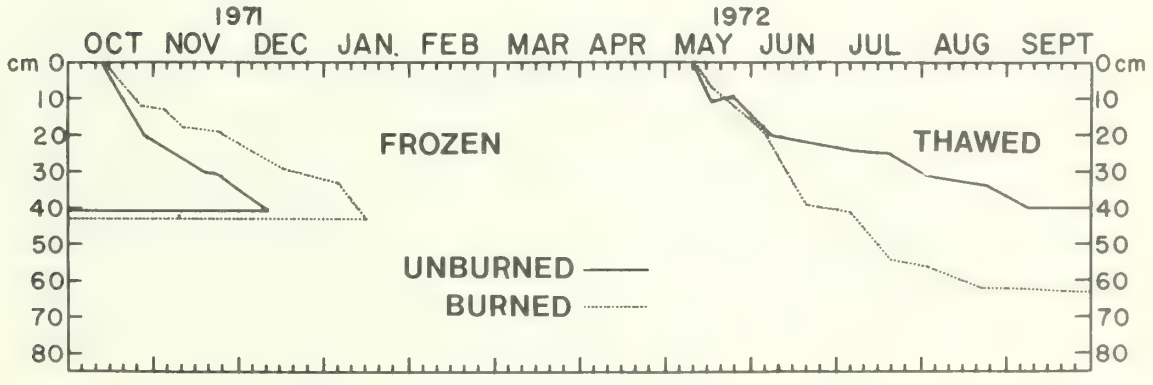


Figure 9.--Freeze-thaw cycle in a heavily burned stand and an unburned control for the 1st year after the fire. (Reproduced from: Viereck, Leslie A. 1973. Ecological effects of river flooding and forest fires on permafrost in the taiga of Alaska. In *North American contribution, permafrost, second international conference, p. 66. Natl. Acad. Sci., Washington, D.C.).*

Figure 10 compares the thawing depths in the heavily burned stands and the unburned controls and on the fireline for the first 3 years after the fire. In the unburned control the thaw patterns are similar each year; maximum thaw depth is approximately 45 cm. Table 5 gives the depth of thaw in the three areas through the summer of 1976.

In the burned stand there has been an increase each year in the maximum depth of thaw and in the rate of thaw (table 5).

The fireline has shown the most dramatic change in the depth of thaw (table 5). In addition, there has been some subsidence from the loss of pure ice deposits so that the actual depth of thaw in relationship to the original surface may be somewhat greater.

In the 5 years after the fire, there seemed to be no slowing down of the annual increase in thaw depth in either the burned stand or the fireline. With complete recovery of the surface vegetation, the depth of thaw is expected to stabilize and eventually return to that of the original stand.

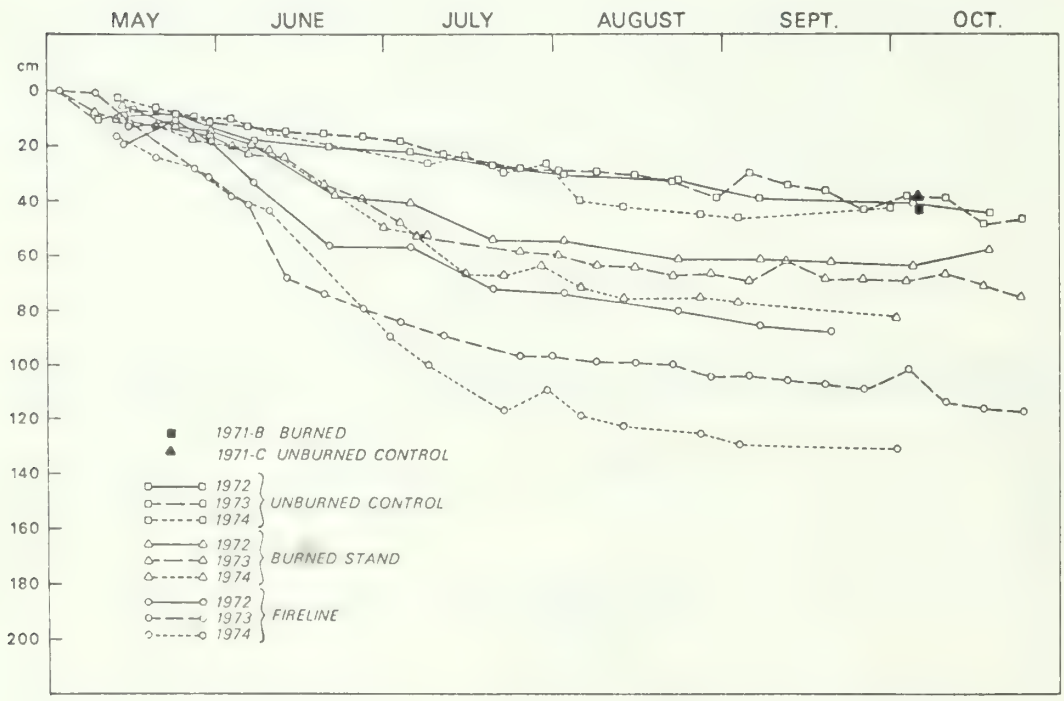


Figure 10.--Depth of thaw in a heavily burned stand, on a cleared fireline, and in an unburned control for 3 years after the fire.

Table 5--Maximum depths of thaw in an unburned control, a burned black spruce stand, and a fireline for the 6 summers after a June 1971 wildfire at Wickersham Dome

Stand and year	Maximum depth of thaw	Percent of thaw in unburned control	Annual increase in depth of thaw
	Centimeters	Percent	Centimeters
Unburned control:			
1971	40		
1972	42		
1973	45		
1974	45		
1975	45		
1976	38		
Burned in June 1971:			
1971	42	105	2
1972	62	148	20
1973	78	173	16
1974	81	180	3
1975	83	184	2
1976	109	286	26
Fireline, June 1971:			
1971			
1972	83	198	
1973	119	264	36
1974	136	302	17
1975	155	344	19
1976	196	515	41

Climatic Factors[9]

Snow depths in burned and unburned forests.

Snow depths were recorded weekly in three burned black spruce stands (BS-3H, BS-1L, and BS-1H) and three unburned controls (BS-3C, BS-1C, and BS-4C) from two snow stakes in each stand. Figure 11 shows the snow depths for the two stands in plot set 3 (BS-3C and BS-3H) (table 2). These stands show a pattern that characterized all six of the sampled stands. In 1971 the first snow fell in late September and by October 14, when all stakes were read the first time, there was 12 cm of snow on the ground.

[9]This section was prepared by L. A. Viereck, Principal Plant Ecologist, and A. E. Helmers, Research Hydrologist (retired), USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

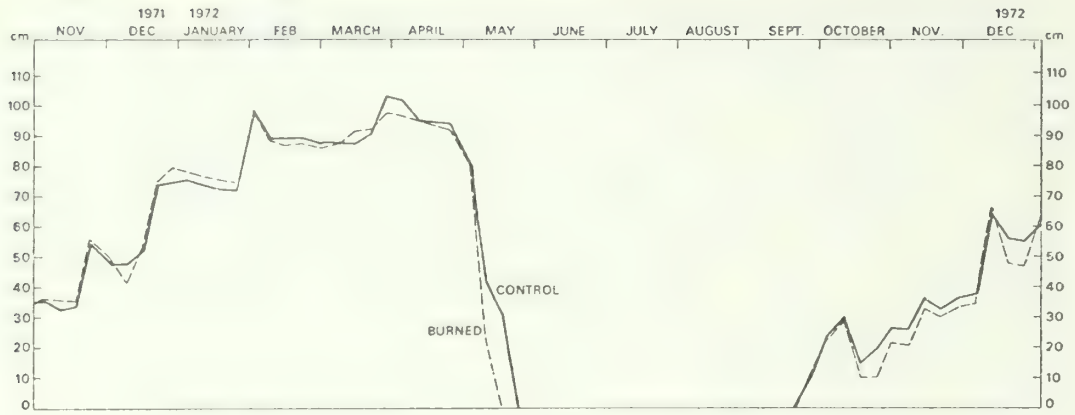


Figure 11.--Depths of snow on burned black spruce stands and unburned controls from November 1971 to December 1972, Wickersham Dome.

Major snowfalls and periods of settlement and compaction can be seen in the steplike curve from November 1 to March 29, the time of maximum snow accumulation (approximately 100 cm in each stand). During this period, there was no significant difference in snow depths between the burned stands and unburned controls.

There was no appreciable snowmelt until the daily mean temperature rose above 0°C at the end of April. Melt was then extremely rapid so that by May 24 all snow was gone from both the unburned control and the burned stand. Snowmelt was much more rapid in the burned stand than in the control. On May 3 both stands had 80 cm of snow; by the following week, the snow in the burned stand had been reduced to 13 cm, whereas that in the unburned control was 42 cm. On May 17 there were only occasional patches of snow in the burned stand, whereas the unburned control still had a nearly continuous cover 13 cm in depth. The burned stand was free of snow about 7 days before the unburned control was. The effect that this had on plant growth was dramatically shown in the lower, heavily burned stand, where clumps of sedge tussocks (*Eriophorum vaginatum* L.) were in full flower on May 17 while there was still a nearly continuous snow cover in the adjacent unburned control.

Snow came early in the fall of 1972. The first snow fell on September 20 and remained on the ground for the rest of the season. This gave a snowfree period of 126 days for the burned stands and 119 days for the unburned controls.

Air Temperature[10]

Air temperatures were recorded with a thermograph in a standard weather bureau shelter in both the heavily burned stand and the unburned control in plot set 3 (table 2). Figure 12 illustrates the average daily air temperature within these stands. There were no significant differences in the shelter temperature between the two stands. The temperatures during this period showed a typical pattern for interior Alaska: occasional intensive cold periods in December, January, and February; and a general warming trend through March, April, and May, with the average daily temperature rising above 0°C at the end of April. The warmest period of the summer was in mid-June, followed by generally lower temperatures in July and August. The daily mean temperature crossed below the freezing point for the first time in mid-September but was above it in an exceptionally warm period in mid-October.



Figure 12.--Average daily air temperature in a burned black spruce stand and an adjacent unburned control.

[10]This section was prepared by L. A. Viereck, Principal Plant Ecologist, and A. E. Helmers, Research Hydrologist (retired), USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

Table 6 provides a monthly summary of the air temperatures from November 1971 to December 1972. In 1972, the average daily temperature was -3.55°C for the burned stand and -3.44°C for the unburned control. This compares with -4.5°C at the Fairbanks International Airport for the same period and -3.5°C for the 30-year average. From these 1971-72 records it appears that the Wickersham Dome area is slightly cooler than Fairbanks in the summer and slightly warmer during the extreme cold periods in winter. This pattern has held in subsequent years. The summaries for 1973 and 1974 are not included in this report but are on file at the Institute of Northern Forestry, Fairbanks.

Table 6--Average air temperatures (°C) in a heavily burned stand and an adjacent unburned control (plot set 3), November 1971 to December 1972

Year and month	Burned stand			Unburned control		
	Average	Maximum	Minimum	Average	Maximum	Minimum
1971:						
November	-14	-11	-17	-15	-12	-18
December	-16	-13	-20	-16	-13	-20
1972:						
January	-22	-19	-25	-22	-19	-25
February	-20	-16	-23	-20	-17	-23
March	-16	-11	-22	-17	-11	-23
April	-8	-2	-13	-8	-2	-13
May	7	12	2	8	13	2
June	14	20	8	14	21	8
July	16	22	11	17	23	11
August	13	17	9	14	19	9
September	4	8	-1	4	8	-1
October	-4	-1	-6	-4	-1	-7
November	-12	-8	-15	-12	-9	-15
December	-15	-12	-18	-16	-13	-18
Average daily temperature for 1972:						
Burned stand	-3.55					
Unburned control	-3.44					

Stream Water Quality[11]

Since most of the burned area drains into Washington Creek, a limited sampling program was initiated on this stream in an attempt to determine the effects of the fire on water quality. F. B. Lotspeich, of the Environmental Protection Agency's Arctic Environmental Research Laboratory, established four water sampling stations

[11]This section was prepared by F. B. Lotspeich, Soil Scientist, Special Studies Branch, U.S. Environmental Protection Agency, Corvallis, Oregon; and C. T. Dyrness, Supervisory Soil Scientist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

on Washington Creek (two below the burned area and two above it) and obtained samples the day the fire was controlled and 1 and 2 weeks after it was controlled. These samples of stream water were analyzed in the laboratory to determine whether the chemical retardants dropped had enriched the water and how much sedimentation resulted from erosion of the firelines. Results were summarized by Lotspeich (1972).

Although measurements of suspended sediment were not obtained for the first set of water samples, the sediment content of Washington Creek below the burned area was estimated to be about 300-500 mg/liter at the time the fire was controlled. The primary source of sediment was thought to be erosion of firelines caused by thawing of the permafrost. Therefore, immediately after the fire, the Bureau of Land Management constructed water bars across firelines in an effort to curtail this form of erosion. These measures were apparently successful; water samples collected several days later were uniformly low in suspended sediment content--the maximum value, 19 mg/liter. Just prior to the third and last sampling (about 2 weeks after control of the fire), sufficient rain fell to cause Washington Creek to rise. Apparently some sediment was still entering the drainage from the bulldozed firelines because at this time maximum sediment content was 97 mg/liter.

Little effect of the chemical retardant could be detected in the water samples. Nitrogen content of samples collected above and below the burned area were about the same. Although amounts of total phosphate in samples collected below the fire were somewhat higher than those in control samples, amounts never exceeded the content recommended for aquatic life in "Water Quality Criteria" (Report of the National Technical Advisory Committee, Federal Water Pollution Control Administration, 1968, p. 27-110).

BIOTIC FACTORS

Vegetation Analysis[12]

One of the main objectives of the Wickersham Dome study was to follow the development of vegetation after the fire. To accomplish this, we followed vegetation trends in all 11 sample stands selected for study in 1971 and 1972 (table 2)--nine stands are in the black spruce type and 2 in aspen.

In each sample stand, 20 permanent plots were located at intervals of 30 m, usually in four rows of 5 plots. Vegetation analysis

[12]This section was prepared by L. A. Viereck, Principal Plant Ecologist, and M. J. Foote, General Biologist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

was slightly modified from a method described by Ohman and Ream (1971). At each location, the cover of ground vegetation, herbs, and low shrubs was determined in a 1-m^2 plot. Tall shrubs were counted and diameters measured in a 4-m^2 plot. Tree seedlings--trees less than 1.3-m in height--were also recorded on the 4-m^2 plot.

Density and basal area of trees and saplings were determined by the point-quarter method. Saplings were defined as trees reaching a height of 1.3 m (b.h.) but having a diameter of less than 2.54 cm.

Computer programs were used to summarize the information. Values of percent frequency, cover, relative frequency, relative cover, and importance were determined for the ground cover, herbs, and low shrubs. Frequency, number of stems per hectare, basal area, relative frequency, relative density, and relative dominance were determined for trees and tall shrubs. These values were determined for all species in each stand.

In addition, data for the four heavily burned stands and the two lightly burned stands were summarized and compared with the summary of all four unburned stands for each year. Finally, data from all stands for each year were run through a clustering program by the agglomerative method (Orloci 1967).

The vegetation changes in selected stands the first 3 years after the fire are shown in tables 7, 8, and 9. In each case the vegetation data for the burned stand are compared with the paired unburned control.

1.--BS-3H and BS-3C are heavily burned and unburned black spruce stands in plot set 3 (table 2).

The outstanding feature of stand BS-3H is the rapid development of the herbaceous cover--from 1 percent during the summer of the fire (1971) to 21 percent by 1974 (table 7 and fig. 13). In contrast, the unburned control had only 3.5-percent herbaceous cover. The moss and liverwort cover returned, mainly because of three species--*Polytrichum juniperinum* Hedw., *Marchantia polymorpha* L., and *Ceratodon purpureus* (Hedw.) Brid., but the return was slow. The moss and lichen species which made up 80 percent of the cover in the unburned control had not returned at the end of 3 years.

Recovery of *Salix scouleriana* has been rapid; density reached a peak of 15,250 stems per hectare in 1973 and declined somewhat in 1974, but the basal area continues to increase. By 1973 the basal area of the willow was equal to that in the unburned control and by 1974 it was nearly three times as large. *Rosa acicularis* was also more abundant in the burn than in the control.

Few species invaded the stand during the 3 years after the fire. Most development was from plant parts that remained alive after the fire. Even fireweed (*Epilobium angustifolium* L.) was present in the control; in the burned stand it developed first from subsurface rhizomes. Later spread has been by both rhizome and seed. Two exceptions to this are the liverwort and moss, *Marchantia polymorpha* and *Ceratodon purpureus*; neither was recorded in the unburned control, but both have spread rapidly in the burned area, primarily on areas of exposed mineral soil.

Table 7--Analysis of vegetation in a heavily burned ridgetop black spruce stand (BS-3H) and an adjacent unburned control stand (BS-3C) in black spruce for 4 years after a 1971 wildfire[1/]

Species	Density					Basal area (m^2/ha) or frequency (percent)				
	1971	1972	1973	1974	Control	1971	1972	1973	1974	Control
	- - -Number of stems per hectare- - -					- -Square meters per hectare- -				
Trees:										
Picea mariana--										
Live trees	0	0	0	0	2,292	0	0	0	0	6.883
Dead trees	1,320	1,179	1,511	1,568	0	0	0	0	0	
Saplings	0	0	0	0	2,024	0	0	0	0	
						- - - -Frequency (percent)- - - -				
Seedlings and layerings	0	250	375	2,750	13,250	0	5	5	20	90
Populus tremuloides--										
Seedlings	0	0	125	0	0			5		
						- -Square meters per hectare- -				
Tall shrubs:										
Salix scouleriana	2,375	8,625	15,250	9,875	2,500	0.05	0.175	0.55	1.7	0.6
Rosa acicularis	1,250	1,625	1,750	2,375	375	.025	.03	.04	.05	.01
Alnus crispa	250	5,000	3,375	3,875	0	0	.088	.06	.21	0
Salix sp.	0	250	0	125	0	0	0	0	--	0
Rubus idaeus	0	0	250	0	0	0	0	--	0	0
Total tall shrubs	3,875	15,375	20,625	16,250	2,875	.075	.30	.66	1.96	.61
	- - - - - -Cover (percent)- - - - - -					- - - -Frequency (percent)- - - -				
Low shrubs:										
Ledum groenlandicum	0.6	1.2	2.10	3.70	4.60	60	70	55	50	80
Vaccinium uliginosum	0	2.7	3.95	5.15	9.45	0	90	70	80	95
Spiraea beauverdiana	0	.25	.05	.25	0	0	25	5	15	0
Vaccinium vitis-idaea	0	.15	.20	.35	6.90	0	15	15	35	100
Ledum decumbens	0	.05	0	0	0	0	5	0	0	0
Chamaedaphne calyculata	0	.05	0	0	0	0	5	0	0	0
Empetrum nigrum	0	0	0	0	.20	0	0	0	0	10
Oxycoccus microcarpus	0	0	0	0	.05	0	0	0	0	5
Total low shrubs	.60	4.40	6.30	9.45	21.20					
Herbs:										
Calamagrostis canadensis	0.80	1.90	2.8	7.50	0.20	75	85	85	75	20
Rubus chamaemorus	.15	.10	.10	.20	0	15	10	10	10	0
Equisetum sylvaticum	.10	1.5	1.35	7.15	.05	10	55	40	60	5
Cornus canadensis	.10	.35	.35	1.80	.35	10	35	25	35	35
Geocaulon lividum	.05	.10	.25	.05	2.60	5	10	15	5	90
Polygonum alaskanum	0	.05	0	0	0	0	5	0	0	0
Mertensia paniculata	0	.05	0	0	0	0	5	0	0	0
Epilobium angustifolium	0	.05	2.95	4.05	.05	0	5	25	55	5
Lycopodium complanatum	0	0	0	0	1.40	0	0	0	0	20
Equisetum arvense	0	0	0	.15	0	0	0	0	10	0
Lycopodium clavatum	0	0	0	0	.80	0	0	0	0	35
Total herbs	1.20	4.10	7.8	20.9	3.51					
Mosses and lichens:										
Polytrichum juniperinum	0	.40	.65	5.10	1.70	0	40	65	45	65
Other mosses	0	.10	0	.10		0	5	0	5	0
Marchantia polymorpha	0	.05	.10	.10		0	5	5	5	0
Ceratodon purpureus	0	0	1.00	1.70		0	0	20	40	0
Dicranum sp.	0	0	.05	0		0	0	5	0	0
Pleurozium schreberi	0	0	0	0	56.25	0	0	0	0	90
Cladonia rangiferina	0	0	0	0	6.05	0	0	0	0	95
Nephroma arcticum	0	0	0	0	6.45	0	0	0	0	35
Aulacomnium palustris	0	0	0	0	2.40	0	0	0	0	60
Peltigera aphthosa	0	0	0	0	2.00	0	0	0	0	50
Cladonia spp.	0	0	0	0	1.20	0	0	0	0	40
Peltigera canina	0	0	0	0	1.80	0	0	0	0	25
Fungi	0	0	0	0	.60	0	0	0	0	55
Cetraria islandica	0	0	0	0	.60	0	0	0	0	20
Hylocomium splendens	0	0	0	0	.50	0	0	0	0	20
Parmelia sp.	0	0	0	0	.25	0	0	0	0	25
Cetraria sp.	0	0	0	0	.10	0	0	0	0	10
Mnium sp.	0	0	0	0	.20	0	0	0	0	5
Total mosses	0	.55	1.80	7.00	61.05					
Total lichens	0	0	0	0	18.45					
Total mosses and lichens	0	.55	1.80	7.00	80.10					
Total ground cover	1.80	9.05	14.90	37.35	104.81					

[1/] -- = negligible

Table 8--Analysis of vegetation in a heavily burned stand (AS-1B) and an adjacent unburned control stand (AS-1C) in aspen for 1972, 1973, and 1974 after a 1971 wildfire

Species	Density				Basal area (m^2/ha) or frequency (percent)			
	1972	1973	1974	Control	1972	1973	1974	Control
	- -Number of stems per hectare- -				Square meters per hectare			
Trees:								
Populus tremuloides--								
Live trees	0	0	0	1,323	0	0	0	20.080
Dead trees	843	847	851	465	0	0	0	
Saplings	0	6,514	27,208	13	0	0	0	
Root suckers	198,375	130,000	8,125	3,875	0	0	0	
Picea glauca--								
Seedlings	0	0	0	2,625	0	0	0	
Picea mariana--								
Live trees	0	0	0	518	0	0	0	1.784
Dead trees	371	397	543	135	0	0	0	
Saplings	0	0	0	578	0	0	0	
Seedlings	0	0	0	1,125	0	0	0	
Betula papyrifera--								
Live trees	0	0	0	233	0	0	0	2.621
Dead trees	134	138	54	76	0	0	0	
Saplings	0	0	0	66	0	0	0	
Seedlings	0	0	0	250	0	0	0	
Tall shrubs:								
Rosa acicularis	4,625	6,000	9,125	1,875	.09	.11	.18	.04
Alnus crispa	500	750	250	5,000	.01	.01	0	1.68
Total tall shrubs	5,125	6,750	9,375	6,750	.10	.12	.18	1.72
	- - - -Cover (percent)- - - -				- -Frequency (percent)- -			
Low shrubs:								
Ribes triste	.05	0	.65	--	5	0	35	
Vaccinium vitis-idaea	0	0	0	5.10	0	0	0	75
Vaccinium uliginosum	0	0	0	2.15	0	0	0	40
Linnaea borealis	0	0	0	2.75	0	0	0	10
Ledum groenlandicum	0	0	0	.65	0	0	0	25
Total low shrubs	.05	0	.65	10.65				
Herbs:								
Corydalis sempivirens	1.15	.05	.05	0	10	5	5	0
Epilobium angustifolium	.45	4.9	12.0	.25	20	90	90	20
Calamagrostis canadensis	.20	.50	6.8	1.45	20	30	90	80
Cornus canadensis	.15	.65	1.5	4.95	15	30	40	100
Pyrola secunda	0	.05	0	0	0	5	0	0
Stellaria sp.	0	0	.1	0	0	0	10	0
Geocaulon lividum	0	0	0	.65	0	0	0	20
Lycopodium sp.	0	0	0	.50	0	0	0	10
Total herbs	2.35	6.2	20.55	7.8				
Mosses and lichens:								
Marchantia polymorpha	.25	6.6	6.9	0	15	40	45	0
Liverwort	.15	0	0	0	10	0	0	0
Polytrichum juniperinum	.05	.05	1.40	.20	5	5	65	10
Fungi	.05	.35	.65	.35	5	35	65	30
Ceratadon purpureus	0	20.9	31.3	0	0	100	80	0
Ptilium ciliare	0	.15	0	.35	0	10	0	10
Other mosses	.75	2.00	0	0	45	5	0	0
Parmelia sp.	0	.10	0	1.25	5	0	0	70
Drepanocladus sp.	0	0	0	3.45	0	0	0	75
Pleurozium schreberi	0	0	0	4.20	0	0	0	25
Hylocomium splendens	0	0	0	1.15	0	0	0	45
Cetraria sp.	0	0	0	.30	0	0	0	30
Peltigera aphthosa	0	0	0	.50	0	0	0	5
Aulacomnium palustris	0	0	0	.10	0	0	0	10
Cladonia sp.	0	0	0	.10	0	0	0	10
Total mosses and lichens	1.25	30.2	40.36	12.55				
Total ground cover	3.65	36.40	61.50	31.00				

Establishment of spruce seedlings has been low in this stand; only 20 percent of the 4-m^2 plots contained any seedlings, and the total was only 2,750 per hectare in 1974. The dead black spruce remained standing, so there was significant decrease in density.

2.--BS-2H, BS-2L, and BS-2C are heavily burned, lightly burned, and unburned black spruce stands in plot set 2 (table 2). These three stands are representative of a black spruce stand underlain by permafrost and with a thick organic layer. Table 8 summarizes the analysis of vegetation for the three stands.

Development of vegetation in the heavily burned stand was similar to that described for stand BS-3H; i.e., slow development of the low shrubs and herbaceous layer. The moss layer developed slowly, and total cover reached 11 percent in 1974--primarily a result of the development of *Ceratodon purpureus*. Density of dead trees did not decrease appreciably after the summer of the fire. Tree seedlings became numerous, approximately 21,000 per hectare in 1974. Resprouting of shrubs was slow; the total number of tall shrubs in the heavily burned stand in 1974 was only a third that of the unburned control.

The lightly burned stand developed in a different manner than the heavily burned stand (fig. 14). A number of trees and saplings survived the fire, but these died during the 3 years after the fire so that only 61 per hectare remained alive at the end of the 1974 season. Because of the presence of extensive area of unburned or partially burned mosses, spruce seedlings germinated in large numbers; nearly 40,000 per hectare were recorded in 1974.

After the fire, nearly 40 percent of the ground cover was still alive in the lightly burned stand. This residual vegetation developed rather rapidly, especially in the summer of 1974, so that there was 70-percent cover by August 1974. Unlike the heavily burned stand, many moss and lichen species of the original stand persisted after the fire, and the cover slowly increased. In addition, the moss cover has been augmented by the growth and spread of *Ceratodon purpurea*. All the *Cladonia* species of lichens survived the light burn, whereas none survived the heavy burn. It appears that the lightly burned stand will return to its original condition much more rapidly than the heavily burned stand.

3.--AS-1B and AS-1C are a heavily burned stand and an unburned control in aspen in plot set 4 (table 2).

The heavily burned stand showed a very rapid revegetation rate, especially in the development of root suckers (table 8). The 1st year after the fire (1972), there were nearly 200,000 aspen shoots per hectare; this dropped to 130,000 in 1973 and to 8,125 per table 8 in 1974. Several other tree species present before the burn--black spruce, white spruce, and paper birch--have not developed seedlings since the fire.

The number of tall shrubs increased rapidly because *Rosa acicularis* spread from stem and root shoots. The low shrubs, although having an 11-percent cover in the unburned control, had less than 1-percent cover 2 years after the fire.

Table 9--Analysis of vegetation in heavily burned (BS-2H) and lightly control stand (BS-2C) in lower slope black spruce

Species	Density								
	Heavy burn				Light burn				
	1971	1972	1973	1974	1971	1972	1973	1974	Control
	Number of stems per hectare								
Trees:									
Picea mariana--									
Live trees	0	0	0	0	697	65	64	61	1,803
Dead trees	4,431	4,739	4,149	4,089	362	1,075	1,161	2,161	0
Live saplings	0	0	0	0	1,896	62	62	62	2,593
Seedlings	0	19,750	17,750	21,375	4,375	28,250	32,125	38,875	23,250
Tall shrubs:									
Salix pulchra	125	1,500	125	1,375	500	2,250	1,250	2,125	3,125
Betula glandulosa	125	1,625	750	1,625	1,125	4,500	1,750	3,375	10,750
Rosa acicularis	0	625	125	375	0	0	0	0	0
Total tall shrubs	250	3,750	1,000	3,375	1,625	6,750	3,000	5,500	13,875
	Cover (percent)								
Low shrubs:									
Vaccinium uliginosum	0.10	1.00	0.70	0.70	2.50	3.80	3.05	5.10	13.85
Ledum groenlandicum	.10	1.15	1.40	2.10	2.15	2.65	1.35	4.15	6.55
Vaccinium vitis-idaea	.05	.50	.30	.90	3.45	3.55	1.65	6.10	20.35
Spiraea beauverdiana	0	.20	0	.10	0	0	0	0	0
Ledum decumbens	0	0	.05	.15	1.45	1.05	1.90	1.30	3.10
Oxycoccus microcarpus	0	0	0	0	3.80	3.90	.75	1.75	2.20
Empetrum nigrum	0	0	0	0	1.40	1.10	.90	1.25	1.90
Total low shrubs	.25	2.85	2.45	3.95	14.75	16.05	11.15	19.65	47.95
Herbs:									
Calamagrostis canadensis	.65	1.35	2.15	4.40	.70	1.50	1.45	5.15	2.20
Rubus chamaemorus	.45	1.0	1.35	2.45	1.90	3.65	2.80	7.35	7.10
Petasites frigidus	.10	.40	.15	.25	.20	.45	.10	.80	.70
Equisetum sylvaticum	0	3.35	3.60	8.95	.10	2.65	2.60	5.70	1.25
Cornus canadensis	0	.10	.15	.20	0	0	0	0	0
Epilobium angustifolium	0	.05	.10	.45	0	0	.55	.10	0
Equisetum arvense	0	0	0	.95	0	0	0	0	0
Equisetum scirpoidea	0	0	0	0	0	0	0	0	1.10
Eriophorum vaginatum	0	0	0	0	.10	.20	.60	0	.05
Pyrola secunda	0	0	0	0	0	0	0	0	.05
Unknown herb	0	0	0	0	.05	.05	0	0	0
Pedicularis labradorica	0	0	0	0	0	0	0	.25	0
Total herbs	1.20	6.25	7.55	17.65	3.05	8.50	7.50	19.95	12.45
Mosses and lichens:									
Polytrichum sp.	.05	1.00	2.80	2.05	1.40	1.70	1.55	5.30	3.65
Fungi	0	.15	.15	.05	0	.25	.10	.35	.95
Marchantia polymorpha	0	.10	.10	.35	0	0	0	0	0
Other mosses	0	.10		.10	.65	0	0	.10	1.85
Ceratadon purpureus	0	0	2.40	8.05	0	0	.10	1.75	.20
Sphagnum spp.	0	0	.05	0	11.65	12.20	7.30	13.50	36.00
Ptilium crista-castrensis	0	0	0	.05	0	0	.50	0	0
Peltigera spp.	0	0	0	.05	0	0	0	0	0
Aulacomnium palustris	0	0	0	.05	.05	1.65	3.75	2.85	14.65
Pleurozium schreberi	0	0	0	0	3.70	5.25	7.45	2.05	27.00
Hylocomium splendens	0	0	0	0	.05	0	0	1.75	4.70
Peltigera canina	0	0	0	0	0	.25	0	.65	3.40
Nephroma arcticum	0	0	0	0	0	.10	0	.10	3.10
Cladonia sylvatica	0	0	0	0	0	.10	0	.20	2.60
Peltigera aphthosa	0	0	0	0	0	.80	0	0	1.95
Cladonia spp.	0	0	0	0	.05	.30	.25	.50	2.05
Dicranum sp.	0	0	0	0	0	.10	0	.05	1.05
Cetraria spp.	0	0	0	0	.15	.20	.15	0	.95
Parmelia spp.	0	0	0	0	.10	.25	.05	.10	.85
Cladonia amaurocraea	0	0	0	0	0	.95	.35	0	.40
Cladonia rangiferina	0	0	0	0	0	.35	.05	.25	.05
Aulacomnium turgidum	0	0	0	0	0	0	0	0	.20
Cetraria islandica	0	0	0	0	0	0	0	0	.40
Unknown foliose lichen	0	0	0	0	0	0	0	0	0
Cetraria pinastre	0	0	0	0	0	0	0	0	.10
Other liverworts	0	0	0	0	0	0	0	0	.05
Total mosses and lichens	.05	1.35	5.50	10.75	19.95	23.60	21.45	30.45	106.05
Total ground cover	1.45	10.45	15.50	32.35	37.75	48.15	40.10	70.05	166.45

burned (BS-2L) stands and in an adjacent unburned for 4 years after a 1971 wildfire

Basal area (m^2/ha) or frequency (percent)								
Heavy burn				Light burn				
1971	1972	1973	1974	1971	1972	1973	1974	Control
-Square meters per hectare-								
0	0	0	0	0.2067	0.3424	0.1388	0.1388	2.804
0	0	0	0	0	0	0	0	0
0	0	0	0	0	.0104	.0108	.0108	.6957
-Frequency-								
0	80	100	90	30	95	95	100	100
-Square meters per hectare-								
0	0.025	0	0.05	0.0125	0.0500	0.0250	0.0375	0.07
0	0	0	.0375	.0250	.0875	.0375	.0625	.05
0	.0125	0	.0125	0	0	0	0	0
0	0	0	.1	.0375	.1374	.0625	.1125	.12
-Frequency-								
10	85	40	35	70	95	75	85	100
10	90	70	65	45	90	80	90	90
5	35	30	40	50	90	80	95	95
0	20	0	10	0	0	0	0	0
0	0	5	10	25	35	65	40	65
0	0	0	0	45	50	25	35	45
0	0	0	0	20	25	10	20	30
65	80	80	85	40	65	70	70	80
40	65	60	60	80	95	40	85	85
10	20	15	20	10	25	5	25	45
0	80	80	90	10	95	95	85	60
0	10	15	10	0	0	0	0	0
0	5	5	10	0	0	10	5	0
0	0	0	15	0	0	0	0	0
0	0	0	0	0	0	0	0	20
0	0	0	0	10	10	10	0	5
0	0	0	0	0	0	0	0	5
0	0	0	0	5	5	0	0	0
0	0	0	0	0	0	0	5	0
5	75	85	75	45	95	80	100	75
0	15	15	5	0	25	10	35	95
0	10	5	15	0	0	0	0	0
0	5	0	5	20	0	0	10	15
0	0	55	60	0	0	10	45	5
0	0	5	0	65	50	35	55	70
0	0	0	5	0	0	5	0	0
0	0	0	5	0	0	0	0	0
0	0	0	5	5	15	15	20	80
0	0	0	0	50	40	30	40	80
0	0	0	0	5	0	0	15	45
0	0	0	0	0	10	0	30	65
0	0	0	0	0	5	0	5	25
0	0	0	0	0	5	0	10	55
0	0	0	0	0	10	0	0	45
0	0	0	0	5	15	5	20	80
0	0	0	0	0	5	0	5	25
0	0	0	0	15	20	15	0	95
0	0	0	0	10	25	5	10	85
.75	0	0	0	20	5	0	15	40
.15	0	0	0	20	5	10	5	5
.15	0	0	0	0	0	0	5	5
.05	0	0	0	0	0	0	10	5
0	0	0	35	0	0	0	0	0
0	0	0	0	0	0	0	10	0
0	0	0	0	0	0	0	5	0



Figure 13.--Heavily burned black spruce stand (BS-3H) 1 year after the fire (August 1972) shows some development of Epilobium angustifolium *L. and* Calamagrostis canadensis.



Figure 14.--Lightly burned black spruce stand 1 year after the fire (August 1972) shows the very conspicuous development of Equisetum sylvaticum.

In contrast, both the herbaceous layer and the moss and lichen cover increased rapidly until, in 1974, they occupied three times the area in the burned stand that they did in the unburned control. It is to be expected that, as the density of the canopy increases and leaf litter accumulates, the cover of mosses will be reduced.

The results of the cluster analysis for the 11 stands for the first 2 years after the fire are shown in figure 15. For purposes of this analysis, a stand was considered new each time it was resampled. At the highest level of within-group dispersion all

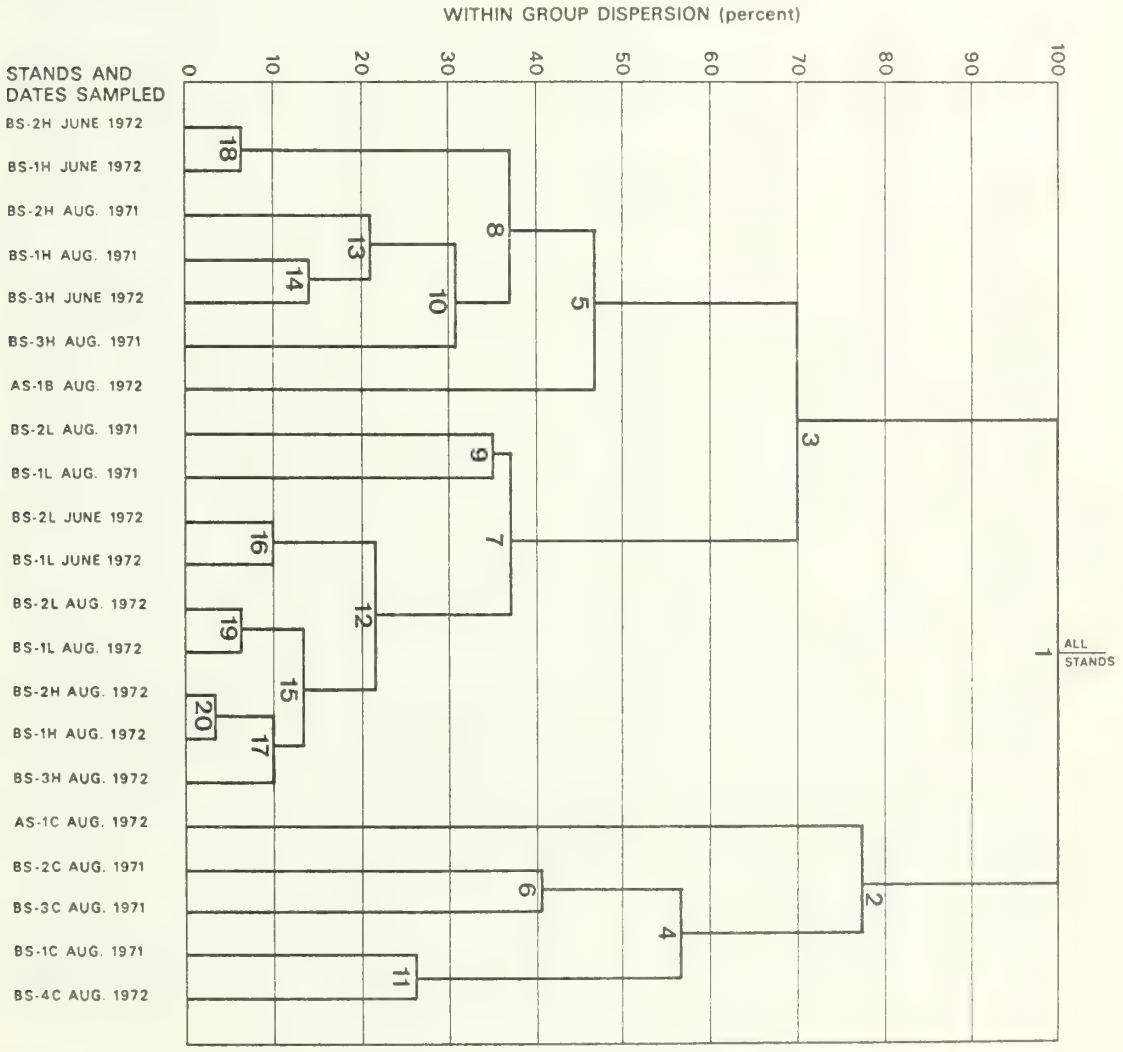


Figure 15.--Results of analysis of clusters of vegetation data (based on twenty 1-m^2 plots) collected in 11 sample stands over a 2-year period after the 1971 Wickersham Dome fire. For the within-group dispersion, a stand was treated as a new stand each time it was sampled. Burned stands were sampled in August 1971, June 1972, and August 1972; unburned controls were sampled only once.

stands were combined into one group. At the next level the stands were separated into two groups which contained all the burned stands in one group and all the unburned control stands in the other (fig. 15, group 2 and 3). Within the control group, the aspen stand is different from all the black spruce stands (group 4). Within the black spruce types, the most similar are two stands on the west-facing slope, one at midslope and the other at the base of the slope. The ridgetop stand (BS-3H) was most similar to the east-facing stand (BS-2H) on the lower slope.

The two lightly burned stands (BS-1L and BS-2L) are more similar to each other at each analysis time than they are to themselves at different sampling times (fig. 15). Also, there is a tendency for the stands to become more similar to each other as time passes. Thus, in August 1971 the within-group dispersion between the two lightly burned stands was 34 percent; in June 1972 it was 10 percent and in August, 5 percent. The same tendency holds true for the heavily burned stands in the bottom of the valley (BS-1H and BS-2H). In August 1971 the within-group dispersion for these two stands was 31 percent; in June 1972 it was 7 percent and in August, only 3 percent.

At the last sampling of the heavily burned stands in August 1972, these stands were grouped with the lightly burned stands rather than with the heavily burned stands from the two earlier inventories.

This tendency for the stands to become more similar as time progresses indicates that the effects of the differences in intensity of burn rapidly become less as the stands develop mature vegetation. We will follow this trend over the next few years.

Biomass[13]

Plant biomass, obtained on a unit area basis, is often a better indication of amounts and proportions of plant species than are some other measurements, such as basal area, density, or cover. Also, it is essential to know the actual amounts of biomass--usually in units of grams per square meter, kilograms per hectare, or metric tons per hectare--as inputs for studies of ecosystem processes, such as primary productivity, decomposition, or simply the flow of any nutrient through the system.

In our fire succession studies, we are interested in biomass for several reasons. Increased primary productivity has always been assumed to be one result of fire in the taiga. According to this hypothesis, a release of nutrients held in the organic layers and an increase in soil temperature result in increased activity of soil organisms and assimilation of nutrients by plant roots.

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[13]This section was prepared by L. A. Viereck, Principal Plant Ecologist, and M. J. Foote, General Biologist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

One way to investigate productivity in successional stands is to record the biomass each year and then determine the amount of increase or decrease in each category. Coupled with this, the amount of biomass discarded by the plants each year--i.e., the litter fall--should also be determined.

At the Wickersham Dome fire study site, we established a minimum program of collection of the aboveground biomass. In 1972, biomass was determined for only one stand, the heavily burned black spruce stand on the ridgetop (BS-3H). In 1973, sampling was expanded to two more heavily burned black spruce stands (BS-1H and BS-2H) in the Cushman Creek Valley and a heavily burned aspen stand (AS-1B). In addition, the unburned control on the ridgetop (BS-3C) was sampled. Ten 1-m^2 plots were systematically located adjacent to the 20 permanent vegetation plots. All herbaceous plants, low shrubs, mosses, and lichens were clipped at ground level. The material was separated by species, ovendried, and weighed. Because of the scattered and clumped nature of the developing vegetation after the fire, the use of 10 plots resulted in low frequencies for many species and an unreliable statistical sampling. Investigations in future studies should use more, smaller plots.

For the large shrub species on the ridgetop plots (BS-3H and BS-3C), a different method was used; 50 stems were collected adjacent to the plot and an average dry weight of stems and leaves was obtained. This was then multiplied by the number of shrubs per hectare, as determined by sampling the vegetation plots, to give the weight per hectare.

Detailed biomass figures for two sets of stands are given in tables 10 and 11 and figure 16. Table 10 compares the heavily burned black spruce stand, BS-3H, for the first 3 years after the fire with comparable figures for the unburned control. Only low shrubs, herbs, grasses, mosses, and lichens are shown. In addition to the biomass in grams per square meter, the frequency in percent for each species in the 10 plots is given.

There was a slow but steady increase in the total biomass of vegetation developing after the 1971 fire. At first, the aboveground live biomass was zero or close to it, since the fire was hot enough to kill all the aboveground material. For the 1st year, the biomass was primarily shrubs, especially Labrador-tea and prickly rose (table 10). These shrubs sprouted from surviving rootstocks and continued to develop slowly so that by the end of the third summer, their biomass was close to that of the low shrubs in the unburned controls. The herbs and grasses, especially bluejoint (*Calamagrostis canadensis*) (Michx.) Beauv. and fireweed, developed more slowly but by the end of 1974 accounted for more than one-half of the biomass. In contrast, the herbs and grasses in the unburned control made up an almost insignificant part of the biomass. The moss and lichen mat, totally destroyed by the fire, was slow to develop. Two mosses and one liverwort (*Polytrichum juniperinum*, *Ceratodon purpureus*, and *Marchantia polymorpha*), considered fire species, have developed slowly. None of the mosses present before the fire, such as *Hylocomium splendens* (Hedw.) B.S.G. and *Pleurozium schreberi*, (Brid.) Mitt. were recorded in the burned stand. Likewise, no lichens were present, although they made up nearly one-third of the biomass of the unburned control.

Table 10--Biomass of low shrubs, herbs, mosses, and lichens of a heavily burned stand (BS-3H) and an unburned control in black spruce on the ridgetop, Wickersham Dome fire area, first 3 summers after the 1971 fire

Species	Frequency				Biomass			
	1972	1973	1974	Control	1972	1973	1974	Control
	--Percent of 10-m^2 plots--				--Grams per square meter--			
Ledum groenlandicum	90	80	70	80	3.3	6.6	17.5	16.4
Calamagrostis canadensis	80	80	80	0	3.0	8.5	10.7	0
Rosa acicularis	30	40	20	0	2.5	9.1	4.4	0
Vaccinium uliginosum	90	70	60	100	2.1	6.8	3.9	11.6
Polygonum alaskanum	10	0	0	0	.6	0	0	0
Equisetum sylvaticum	50	50	50	0	.6	3.9	5.4	0
Rubus chamaemorus	10	10	10	0	.2	.03	.2	0
Cornus canadensis	20	30	30	10	.1	.2	2.2	.02
Polytrichum juniperinum	60	60	40	80	.05	1.1	1.0	3.7
Vaccinium vitis-idaea	50	50	60	90	.04	.08	1.4	5.1
Epilobium angustifolium	10	40	60	0	.02	2.5	25.0	0
Spiraea beauverdiana	10	0	0	0	.01	0	0	0
Marchantia polymorpha	0	10	10	0	0	.1	.8	0
Geocaulon lividum	0	10	0	0	0	.03	0	0
Ceratodon purpureus	0	10	20	0	0	.6	1.3	0
Pleurozium schreberi	0	0	0	100	0	0	0	52.9
Nephroma arctica	0	0	0	70	0	0	0	36.9
Cladonia spp.	0	0	0	70	0	0	0	9.0
Hylocomium splendens	0	0	0	80	0	0	0	8.1
Dicranum sp.	0	0	0	60	0	0	0	3.6
Cetraria islandica	0	0	0	60	0	0	0	2.2
Peltigera aphthosa	0	0	0	20	0	0	0	2.0
Lycopodium annotinum	0	0	0	30	0	0	0	.8
Empetrum nigrum	0	0	0	40	0	0	0	.8
Aulacomnium palustre	0	0	0	10	0	0	0	.01
Drepanocladus sp.	0	0	0	10	0	0	0	.01
Other mosses	0	0	0	10	0	0	0	.2
Total low shrubs					8.2	22.6	27.4	33.9
Total herbs and grasses					4.3	15.1	43.3	.8
Total mosses					.05	1.8	3.1	68.5
Total lichens					0	0	0	50.1
Total					12.5	39.5	73.8	153.3
Annual increment					12.5	27.0	34.3	

Table 11--Biomass of Scouler willow (*Salix scouleriana*) in a heavily burned black spruce stand[1/]

Plant component	1972	1973	1974
Leaves (g/stem)	5.1	14.1	20.0
Wood (g/stem)	6.2	36.8	66.4
Total (g/stem)	11.3	50.9	86.3
Stem density (number/m^2)	.8520	1.525	.9875
Leaves (g/m^2)	4.3	21.5	19.7
Wood (g/m^2)	5.3	56.2	65.5
Total (g/m^2)	9.6	77.6	85.2
Annual increase (g/m^2)	9.6	68.0	7.6

[1/]Based on density of shrubs from vegetation survey and average weights of 50 stems collected adjacent to the stand.

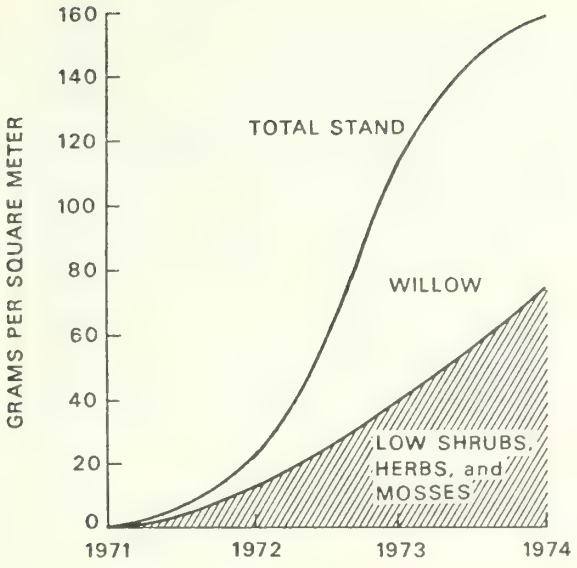


Figure 16.--Biomass of a heavily burned black spruce stand (BS-3H) for 4 years after the 1971 fire.

Table 11 shows the development of the biomass of the Scouler willow in the same stand. After the fire, the willows developed entirely from stump shoots--four to six times as many stems as had been growing previously. In spite of having been trimmed to the ground by snowshoe hares in the fall of 1971, they produced 11 g of biomass per stem in 1972. This increased, so that by the end of 1974, each stem averaged 86 g, about one-fourth of which was leaves and the rest woody material.

On an area basis, there was a rapid increase in biomass of the willows, especially between 1972 and 1973--68 g/m^2 (table 11). Between 1973 and 1974, there was a reduction in the number of stems per hectare because of overcrowding and thinning within the individual clumps. Therefore, the biomass increment slowed down (to 7.6 g/m^2). Figure 16 shows graphically the increase in biomass in this stand for the 3 years after the fire.

The development of biomass in the burned aspen stand has been large compared with that in the black spruce stand. Approximately 60 percent of the biomass in the burned aspen stand is from aspen shoots (table 12). Fire moss (*Ceratodon purpureus*) and liverwort (*Marchantia polymorpha*), however, have also developed and spread, as well as fireweed and blue joint, resulting in a large annual increment in spite of heavy cropping by moose and snowshoe hare. In the winter of 1972-73, every aspen stem was clipped at snow level; however, this heavy browsing seemed to have little effect on shoot growth the following summer and seemed to encourage the development of lateral branches. This very high production of browse on a good site illustrates the value of fire in the production of wildlife habitat.

Table 13 shows the biomass in the four heavily burned stands and gives a rough indication of the annual net increment of the

Table 12--Biomass of a heavily burned aspen stand (AS-1B) during the 2d and 3d summers after a June 1971 wildfire

Species	Frequency		Biomass	
	1973	1974	1973	1974
	Percent in 1-m^2 plots		Grams per square meter	
Ceratodon purpureus	20	100	11.8	114.5
Epilobium angustifolium	70	70	9.5	21.2
Corydalis sempervirens	20	10	.8	.06
Calamagrostis canadensis	40	40	.9	24.8
Rosa acicularis	20	0	.6	9.0
Marchantia polymorpha	20	40	.5	69.6
Cornus canadensis	30	50	.08	3.4
Polytrichum sp.	10	0	.05	0
Rubus chamaemorus	30	0	.02	0
Picea mariana	10	0	.01	0
Fungi	0	40	0	1.9
Viburnum edule	0	10	0	24.0
Total - mosses, herbs, and shrubs	90	90	24.26	268.46
Populus tremuloides:				
Leaves			96.5	102.2
Stems			357.9	434.8
Total			454.4	537.0
Total for stand			478.66	805.46
Annual increment			239.33	326.86

Table 13--Total biomass in four heavily burned stands at the Wickersham Dome fire site, 1972-74[1/]

Stand	Biomass		
	1972	1973	1974
	Grams per square meter		
BS-2H:			
Standing crop	--	17	33
Annual increment	--	8.5	16
BS-3H:			
Standing crop without *Salix*	12	40	74
Annual increment without *Salix*	12	28	34
Standing crop with *Salix*[2/]	22	117	159
Annual increment with *Salix*	22	95	42
BS-1H:			
Standing crop without moss	--	63	92
Annual increment without moss	--	31.5	29
Standing crop with moss[3/]	--	86	118
Annual increment with moss	--	43	32
AS-1B:			
Standing crop	--	479	804
Annual increment	--	239.5	325

[1/] -- = no data.

[2/] Includes *Salix scouleriana* sampled by average weight and density.

[3/] Includes unburned sphagnum clumps.

biomass for each stand. Increase in biomass in the three black spruce stands was extremely low compared with the more productive aspen stand. Even in the ridgetop stand (BS-3H) where the growth of *Salix scouleriana* was rapid, production was not high on an area basis because the density of the original clumps was low. Productivity in the two lowland black spruce stands was low. In stand BS-2H, 3 years after the fire, the biomass was only 33 g/m^2. This area was the most heavily burned, and neither fireweed nor *Calamagrostis* has developed extensively; growth of shrubs, primarily resin birch (*Betula glandulosa* Michx.) and Labrador-tea, has also been slow.

In stand BS-1H there were many *Sphagnum* mounds that did not burn. These have been growing slowly since the fire. For this stand, two biomass figures are given (table 13)--including the moss biomass and excluding it--since the *Sphagnum* did not develop from zero aboveground biomass as the other species have. The biomass for BS-3H is shown with and without Scouler willow because this was the only black spruce stand to develop an extensive tall shrub layer.

Litter Fall[14]

Annual litter fall, the plant material that falls to the ground each year, has been shown to be closely related to productivity in many ecosystems. Many studies of litter fall have been made throughout the world. Any study of primary productivity within an ecosystem must have information on litter fall to distinguish gross and net primary production. Knowledge of litter fall--how material moves from the living, aboveground biomass into the soil organic layers--is also essential in studies of the flow of nutrients and the process of decomposition.

At the Wickersham Dome fire area, samples of litter fall were collected in both burned and unburned stands. The objective was to determine differences in the production of litter as the vegetation develops and to compare characteristics of litter in burned stands with those in unburned stands.

Ten 1/4-m^2 litter trays were placed in each stand. The material from the trays was collected at the beginning and end of each summer season. This material was separated by species and parts and then ovendried. Final results were expressed as grams per square meter.

In June 1972, 70 trays were placed in seven black spruce stands: three heavily burned stands (BS-1H, BS-2H, and BS-3H), two lightly burned stands (BS-1L and BS-2L), and two unburned stands (BS-2C and BS-3C). In June 1973, 30 trays were set out in three other stands: a heavily burned aspen stand (AS-1B), an unburned aspen stand (AS-1C), and an unburned black spruce stand (BS-4C).

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[14]This section was prepared by L. A. Viereck, Principal Plant Ecologist, and M. J. Foote, General Biologist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

Originally, the fall collection was to be made after the year's leaf fall. In 1972 and in 1974, however, the first snow came before leaf fall was complete, making it impossible to obtain a complete fall collection of litter. Therefore, future collections will be made only in the spring after snowmelt. All data will be summarized from June of one year to June of the next year.

Small (1/4-m^2) trays are inadequate for sampling large litter, such as branches or whole trees. To obtain some idea of the large litter in the burned stand at ridgetop stand BS-3H, we established a series of five 10-m^2 plots. All loose litter larger than 1-cm diameter was removed in June 1972. Each succeeding year the litter was collected from these plots and weighed.

A summary of the total litter fall for each stand, as well as an average for burn categories, is shown in table 14. In the unburned black spruce stands litter fall was low, amounting to approximately 10 g/m^2 per year.

Table 14--Litter fall in burned and unburned stands for 3 years after the 1971 Wickersham Dome fire

Stand	Collection period					
	June to Sept. 1972[1/]	Oct. 1972 to June 1973	Year, June 1972 to June 1973	June to Sept. 1973	Oct. 1973 to June 1974	Year, June 1973 to June 1974
	Grams per square meter					
			BLACK SPRUCE			
Heavily burned:						
BS-1H	--	5.12	5.12	2.08	0.44	2.52
BS-2H	--	3.64	3.64	1.76	.08	1.84
BS-3H	8.84	3.16	12.00	3.36	2.68	6.04
Average			6.92			3.47
Lightly burned:						
BS-1L	14.40	4.48	18.88	6.48	2.20	8.68
BS-2L	--	21.04	21.04	1.08	2.24	3.32
Average			19.96			6.00
Unburned control:						
BS-2C	--	5.32	5.32	4.64	.48	5.12
BS-3C	4.60	9.40	14.00	13.80	3.24	17.04
Average			9.66			11.08
			ASPEN			
Heavily burned:						
AS-1B	[2/]	--	--	108.84	8.72	117.56
Unburned control:						
AS-1C	[2/]	--	--	153.40	22.96	176.36

[1/]-- = negligible amount.

[2/]Litter trays were not set out until June 1973.

Litter fall in the burned black spruce stands originated primarily from dead standing trees and from willows. Litter from the low shrubs and herbs was localized; stature of these plants is often too low to allow deposition in the trays. Litter fall in the lightly burned areas was heaviest the second summer after the fire; it dropped off during the 3d year. Litter fall in the heavily burned stands followed a similar pattern but was less abundant compared with that in the light burn. Most of the needles and small branches and cones were not consumed in the lightly burned stands, whereas in the heavily burned stands they either were consumed or dropped to the ground the first summer.

The rate of litter fall is expected to accelerate as the bark begins to slough off the standing dead trees and as small branches and cones fall. Eventually, as the shrubs become larger and more numerous and when the developing spruce seedlings become taller, the litter fall rate should increase to at least that of the unburned stand.

In the burned aspen stand, litter production was relatively high, 118 g/m^2 per year, because of rapid development of the aspen sucker shoots. Growth of these shoots was so rapid in 1974 that the litter in the 1974-75 collection year may nearly equal that of the unburned controls.

The large litter, 1-cm diameter and larger, was sampled in only one heavily burned black spruce stand. The original quantity of large litter in these plots when they were established in the summer of 1972 was 218 g/m^2 (range 19 to 614). A second collection in September 1973 yielded only 4.3 g/m^2 (range 1 to 8.2). Collections will be continued on a yearly basis.

Litter Decomposition[15]

To determine relative rates of litter decomposition, we established a series of litterbags in two heavily burned stands and two unburned controls in the fall of 1972. These bags were to be collected over a period of 5 years and their contents analyzed.

Three species were used for the litter. Needles were collected from black spruce growing on the site, and 20-g samples were placed in 30- by 30-cm nylon mesh bags. Leaves were collected from both bog blueberry and Labrador-tea; 5-g samples of each were placed in nylon mesh bags measuring 15 cm on each side.

The series was repeated four times at each stand. At each site eight bags for each species were stapled to a wire running along the ground. In all, 32 bags for each species were placed in each stand. Collections were made twice yearly, in spring and late fall, for the next 3 years and in the fall only for the following

[15]This section was prepared by L. A. Viereck, Principal Plant Ecologist, and M. J. Foote, General Biologist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

2 years. The first collections were made in May 1973. The samples were analyzed in the laboratory and results compared with data on original weight and nutrient content.

Table 15 summarizes the weight loss of the litterbags for the first 2 years after the bags were placed in the stands. Losses of biomass for the spruce needles and Labrador-tea leaves are similar, 30-31 percent. The blueberry leaves lost slightly more weight, about 37 percent. As would be expected, the weight loss was more rapid during summer than winter. There was no appreciable difference in weight loss between the litterbags in the burned stands and those in the unburned controls.

Table 16 summarizes the nutrient content of the original sample (based on two analyses) and of the samples from May and September 1973. At the time we wrote this report, the analyses of the 1974 collections were not complete, and any conclusions about differential rates of nutrient loss between the three litter samples or between the burned stand and unburned control would be premature.

In addition to analysis of the major nutrients, the samples were analyzed for lignin, acid detergent fiber, and ash content (table 17). In general, percent of weight loss of lignin from litterbag material has been found inversely related to the initial content of lignin. Unfortunately, the original samples were not analyzed for these three substances. There was probably no significant change, however, in lignin content the first winter--August 1972 until late April 1973. Spruce needles, with a lignin content of 14-18 percent, would be expected to decompose more rapidly than blueberry leaves with a lignin content of 26-32; but weight loss data indicated that blueberry leaves decomposed more rapidly than spruce needles.

At the end of this 5-year study of litter decomposition, it will be possible to compare decomposition rates between the burned stands and the unburned controls and among the litter from the three species. It is also expected that differences in the rate of release of the various elements can be compared. The general rate of decomposition of contents of the litterbags will also be compared with the contents of the litterbags from other studies in more temperate locations.

Black Spruce Seed Fall and Seedling Establishment[16]

Black spruce cones are semiserotinus; that is, they remain on the tree and open slowly, thus dispersing seed over a period of years. Therefore, provided trees are producing seed, some seed is always present on the trees (Heinselman 1957). If the cones are not destroyed by fire, this habit makes black spruce well adapted for reseeding burned over areas. It is the only interior

[16]This section was prepared by J. C. Zasada, Silviculturist, L. A. Viereck, Principal Plant Ecologist, and M. J. Foote, General Biologist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

Table 15--Weight loss of litterbags for 2 years after their installation in burned stands and their unburned controls[1/]

Litter	Aug. 1972	May 1973	Sept. 1973	May 1974	Sept. 1974	Weight loss after 2 years
	- - - -Grams dry weight- - - -					Percent
Picea mariana needles:						
Unburned controls	20.0	16.9	15.0	14.7	13.8	31.3
Burned stands	20.0	16.5	14.8	14.4	13.8	31.1
Ledum groenlandicum leaves:						
Unburned controls	5.0	4.3	3.9	3.9	3.5	30.3
Burned stands	5.0	4.3	3.8	3.7	3.5	30.6
Vaccinium uliginosum levels:						
Unburned controls	5.0	3.9	3.4	3.4	3.2	37.0
Burned stands	5.0	4.0	3.4	3.5	3.1	37.4

[1/]Each value is an average of 8 bags.

Table 16--Original (fall 1972) nutrient content of leaves and needles in litterbags from burned stands and unburned controls and the nutrient content after 1 winter and 1 summer of decomposition, Wickersham Dome fire site[1/]

Nutrient	*Vaccinium uliginosum* leaves			*Ledum groenlandicum* leaves			*Picea mariana* needles		
	August 1972	May 1973	September 1973	August 1972	May 1973	September 1973	August 1972	May 1973	September 1973
	- - -

Table 17--Lignin, acid detergent fiber, and ash content of leaves and needles from burned stands and unburned controls after 1 winter and 1 summer, Wickersham Dome fire site, 1973[1/]

Content	*Vaccinium uliginosum*[2/]		*Ledum groenlandicum*[2/]		*Picea mariana*[3/]	
	May	September	May	September	May	September
	- - -

So that we could determine the total amount of black spruce seed potentially available within the burn, trees were felled in November 1971 and September 1972 and all their cones removed. Seeds were removed from the cones according to methods outlined by the USDA Forest Service (1948). The total number of seeds was determined by counting seeds in four 1-g subsamples for each tree and then multiplying that number of seeds by the total weight of seed for that tree. Germination tests were conducted on four 100-seed replications from each tree.

Quantity and quality of dispersed seed[17]

Total seed fall for the 2 3/4-year period was greater in the three burned stands than in the unburned control. Because of the large within-stand variation, however, seed fall for only the light burn was significantly higher than for the control ($p=0.05$). During the 1st year of the study, seed fall in all burned stands was significantly higher than in the unburned control ($p=0.05$). From September 1972 to June 1974, the amount of seed fall in the unburned control was significantly higher than in one heavily burned stand but not significantly higher than in the other two burned stands (table 18).

Table 18--Quantity and quality of black spruce seed dispersed between September 1971 and June 1974 in 3 burned stands and an unburned control at the Wickersham Dome fire site[1/]

Stand	Total seeds per square meter			Filled seeds			Real germination		
	Sept. 1971 to Sept. 1972	Sept. 1972 to June 1974	Total	Sept. 1971 to Sept. 1972	Sept. 1972 to June 1974	Total	Sept. 1971 to Sept. 1972	Sept. 1972 to June 1974	Total
	-Number-			-Percent-					
BS-3C, unburned	85 ± 14b	132 ± 22ab	218 ± 33b	46 ± 4a	48 ± 7ab	47 ± 5a	94 ± 3a	65 ± 10ab	77 ± 5ab
BS-1L, lightly burned	386 ± 39a	120 ± 20ab	507 ± 23a	50 ± 2a	53 ± 3ab	50 ± 2a	87 ± 2a	84 ± 4a	87 ± 1a
BS-1H, heavily burned	289 ± 15a	75 ± 9b	364 ± 22ab	43 ± 3a	56 ± 2a	75 ± 2b	75 ± 2b	58 ± 4b	70 ± 2bc
BS-3H, heavily burned	319 ± 64a	142 ± 11a	461 ± 72ab	42 ± 3a	36 ± 5b	43 ± 2a	68 ± 2b	51 ± 5b	63 ± 2c

[1/]Values followed by the same letters in a column did not differ significantly at the p=0.05 level; plus or minus signs indicate standard error of the mean.

[17]This section was prepared by J. C. Zasada, Silviculturist, L. A. Viereck, Principal Plant Ecologist, and M. J. Foote, General Biologist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

In interpreting these data, the reader must realize that the flat seed traps were not installed until about 2 months after the fire. Thus, the amount of seed dispersed relatively soon after the fire is not known. Wilton (1963) reported that about 370 black spruce seeds per square meter (3.7 million/ha) were dispersed in a 60-day period after an August 25 fire in Newfoundland. He concluded that this was probably less than half the available seed in the stand.

Real germination (the percentage of filled seeds which actually germinated) of seed dispersed during the 1st year was greatest in the unburned control and the lightly burned stand. For the whole study, real germination in the light burn was significantly greater than in either of the heavy burns; in the unburned control it was significantly greater than in only one of the heavy burns (table 18). These data suggest that the fire may have affected germination. This is not unexpected when the burning intensity is considered. For example, the lightly burned stand was chosen partially on the basis that all of the needles were not consumed; some trees with green needles even remained after the fire. In contrast, the needles and fine branches were consumed in the heavily burned stands. This indicates that cones on the trees in the heavily burned stands were subjected to more intense heat than those in the lightly burned stand. Thus, it would be expected that seed quality might be affected in heavily burned areas.

Estimates of seed fall obtained with tall traps were different from those obtained with flat traps. For the same time period, these estimates were 450 and 320 seeds per square meter in the heavy burn for the tall and flat traps, respectively, and 147 and 85, respectively, in the unburned control. Because of variation from trap to trap, however, the estimates within each burn category were not significantly different ($p=0.05$). There are several reasons for the possible differences, and these should be considered in future studies of seed fall. First, the design of the flat trap may have allowed the wind to blow some seeds out of the traps. In fact, on windy days movement of seeds in the traps was observed. In the tall traps, on the other hand, the seeds dropped into a receptacle at the bottom of the trap and were not affected by wind after they entered the trap. A second reason is the different sequence of collection: The tall traps were collected weekly and the flat traps only monthly during the summer and in the spring after snowmelt. Thus, when snow temporarily covered the tops of the traps, the weekly removal of the snow may have resulted in fewer seed being blown away.

Annual pattern of seed dispersal[18]

Seed dispersal patterns for a 1-year period (February 1972 to February 1973) for one of the heavy burns and the unburned control

[18]This section was prepared by J. C. Zasada, Silviculturist, L. A. Viereck, Principal Plant Ecologist, and M. J. Foote, General Biologist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

were similar. The seed fall (total and filled seeds) was much greater, however, on the heavy burn than on the unburned control (fig. 17). These findings suggest that the fire did not affect the annual dispersal pattern for the year after the fire, but it apparently resulted in more cones opening (or opening more fully) and dispersing seed during periods of normal peak dispersal in unburned stands. The main controlling mechanism for the annual dispersal pattern is probably the opening and closing of cones in response to changes in atmospheric humidity and temperature. This is known to occur in Sitka spruce (Harris 1969) and white spruce but has not been observed in black spruce.

Seeds on trees.--The number of seeds present in old and new cones was highly variable in the unburned control. New cones averaged almost twice as many seeds as old cones; however, old cones contained more than 26,000 seeds per tree (table 19).

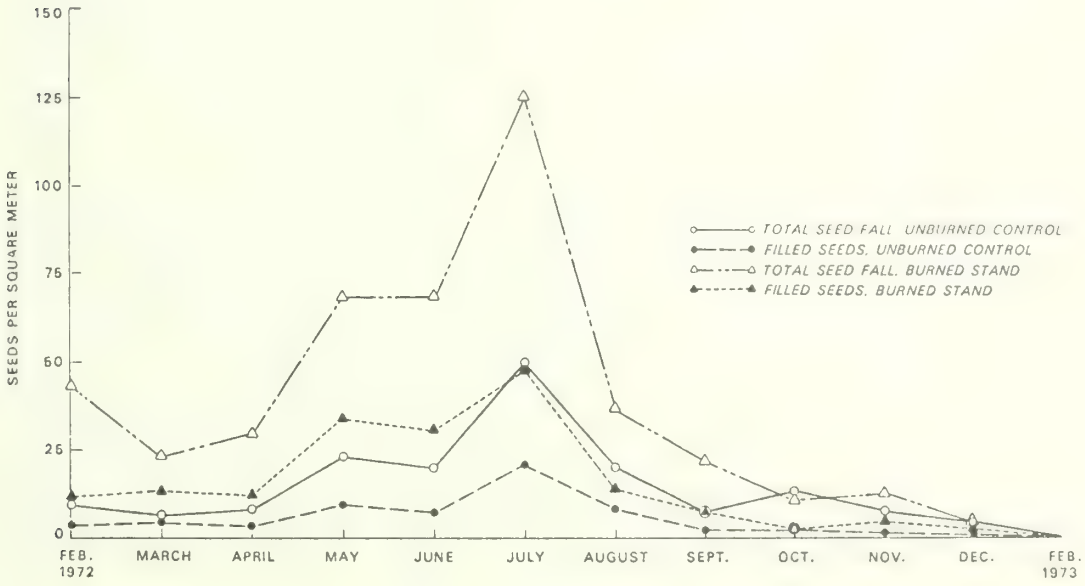


Figure 17.--Seed fall in burned and unburned black spruce stands from February 1972 to February 1973.

In the burned stand, large quantities of seed remained on the trees 1 year after the fire. Because of the large variation among trees in the burned and unburned stands, we cannot draw any conclusions concerning the percentage of seed dispersed the 1st year.

The real germination percentages indicate, as they did for seed collected in seed traps during the 1st year of the study (table 18), that fire reduced the quality of the seed contained in black spruce cones. Real germination averaged 90, 65, and 32 percent for seeds collected from unburned trees and from 1- and 2-year-old burned trees, respectively. In the unburned control, 6 of the 7 trees (86 percent) had real germination of 90 percent or higher, whereas in the burned sample only 6 of 25 (24 percent) had real germination of 90 percent or higher (table 20).

Table 19--Quantity and quality of seed contained in cones of burned and unburned black spruce trees

Stand	Number of sample trees	Old cones[1/]			New cones		
		Number per tree	Seeds per cone	Seeds per tree	Number per tree	Seeds per cone	Seeds per tree
Unburned control:							
Average	[illegible]	208	[illegible]4	5,000	278	40	11,996
Standard deviation		297	9	9,502	[illegible]34	7	12,067
Range		[illegible]-[illegible]40	2-31	105-26,246	30-729	35-49	1,352-35,277
Burned stand, sampled in 1971:							
Average	15	623	15	9,060			
Standard deviation		[illegible]	9	[illegible],47[illegible]			
Range		160-1,660	2-32	850-28,537			
Burned stand, sampled in 1972:							
[illegible]	10	1,168	10	12,352			
Standard deviation		875	3	11,560			
Range		93-2,111	5-13	850-27,020			

[1/] Old cones appeared to be older than 1 or 2 years; new cones were produced in 1970 and 1971; all cones collected from the burned stands were classified as old.

[2/] 10 trees were sampled, but only 7 had cones.

Although the seed testing rules do not recommend stratification for germination trials in black spruce, seed dormancy has not been adequately examined in northern genotypes of this species. Thus, it is possible that some of the poor germination could be the result of seed dormancy. Future tests should include stratification treatments until dormancy patterns are well known.

Seedling establishment.--The success of forest regeneration is determined by seed supply and the biotic and abiotic variables generally referred to as site conditions. Using seedling counts obtained from the vegetation analysis (table 21) and the seed fall data, we can gain some insight into the question of adequacy of seed supply, expressed in seedling percent (seedlings/100 viable seeds), for these site conditions.

Stand	Viable seeds/m^2	Number of seedlings/m^2	Seedling percent
BS-1L (light burn)	220	3.9	1.8
BS-1H (heavy burn)	114	1.2	1.0
BS-3H (heavy burn)	125	.3	.2

These seedling percents are quite low compared with those reported by Johnston (1972) for black spruce regeneration on various seed bed types in northern Minnesota. Because of the variability associated with both the seed fall and estimates of seedling density, the estimates of seedling percent also have a high degree of variability.

Table 20--Average quality of seed from black spruce trees in an unburned control and in a burned stand sampled twice after the 1971 Wickersham Dome fire

Tree number	Filled seed		Germinated seed		Real germination	
	Percent	Standard deviation	Percent	Standard deviation	Percent	Standard deviation
Unburned control:						
1	40.2	6.9	39.2	6.9	97.5	1.9
2	53.5	11.7	51.0	13.3	95.3	5.8
5	39.0	5.7	21.2	5.1	54.4	16.5
7	66.2	7.4	63.5	7.0	95.9	2.6
8	60.5	3.9	60.2	3.6	99.6	.8
9	53.0	5.1	47.8	4.9	90.1	2.9
10	73.0	7.7	72.8	8.2	99.6	.8
Mean	55.1		50.8		90.3	
Burned stand, sampled in 1971:						
1	48.4	10.0	43.6	8.0	90.1	2.7
2	62.7	3.3	27.6	3.5	44.0	5.6
3	50.3	14.7	37.2	19.9	74.0	27.2
4	53.1	8.0	40.6	4.7	76.2	3.5
5	45.6	2.2	25.1	3.7	54.0	7.1
6	67.5	9.6	58.7	15.8	86.8	15.1
7	53.6	13.1	49.4	10.5	93.9	4.7
8	47.0	6.0	8.9	4.5	18.9	9.3
9	45.6	14.8	8.4	3.7	16.1	10.1
10	65.1	4.5	63.9	4.3	98.2	1.5
11	50.1	10.1	13.1	3.4	26.1	4.0
12	68.4	6.3	56.1	5.0	82.1	3.2
13	54.5	10.0	25.1	3.6	46.1	6.4
15	75.0	6.1	71.4	6.3	95.2	.7
16	30.6	2.1	24.9	4.8	81.4	12.3
Mean	54.5		36.9		65.5	
Burned stands, sampled in 1972:						
18	25.8	10.4	1.8	1.0	7.2	2.9
19	38.2	5.2	5.0	.8	13.2	2.5
20	33.5	11.1	31.8	10.9	94.7	3.8
21	64.5	1.3	62.8	1.5	97.3	1.5
22	29.5	14.6	8.2	2.5	27.8	28.8
23	44.5	8.7	3.8	2.5	8.6	5.4
24	48.5	70.0	.8	1.0	1.5	2.1
25	52.8	4.0	32.5	8.7	61.1	13.0
26	36.0	6.0	2.5	1.9	6.5	4.4
27	39.0	10.5	0	0	0	0
Mean	41.2		14.9		31.7	

Table 21--Average number of seedlings in three burned black spruce stands for 3 years after the 1971 Wickersham Dome fire

Year	Stand		
	BS-1L	BS-1H	BS-3H
	Seedlings per square meter		
1971	0	0	0
1972:	3.2	1.4	.02
Standard deviation	3.1	2.0	.11
Range	0-25	0-6	0-.5
1973:	4.2	2.0	.04
Standard deviation	4.5	2.4	.17
Range	0-21	0-7	0-1
1974:	3.9	1.2	.3
Standard deviation	4.0	1.3	.9
Range	0-24	0-4	0-4

Autecology of 1st Year Postfire Tree Regeneration[19]

The type of regeneration after a fire is determined by the percentage of the organic mat consumed (this directly affects seed bed conditions and the material available for vegetative reproduction), the ability of the preburn vegetation to reproduce, and the supply of seed within or adjacent to the burn. The objectives of this study were to examine the dynamics of tree seed germination and first growing season survival on the various seed beds in the burned stands, and to record natural regeneration on randomly selected surfaces of the burn.

Artificial seeding.--The primary site for the artificial seeding study was about 3 km from the Wickersham Dome ridgetop study area (stands BS-3C and BS-3H). A north and south slope (same drainage) were selected for plot establishment; 10 plots were seeded on each aspect. Each plot consisted of five rectangular subplots (5- by 30-cm). The two side subplots and the middle subplot were seeded with 1,000 seeds of either black spruce, white spruce, or paper birch. The black spruce seed were collected from trees in the burned area and had an average germination of 41 percent.

[19]This section was prepared by S. F. Clautice, Forester, Alaska Division of Forest, Lands, and Water Management, Fairbanks; J. C. Zasada, Silviculturist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska; and B. J. Neiland, Professor, School of Agriculture and Land Resources Management, University of Alaska, Fairbanks.

The birch and white spruce seeds were collected in the Bonanza Creek Experimental Forest at an elevation of about 200 m. Laboratory germination was 68 and 27 percent for white spruce and birch, respectively. Plots were seeded in early June 1972 on mineral soil, ash, and charred surfaces.

The second part of the artificial seeding study was conducted on a fireline adjacent to the ridgetop study site at Wickersham Dome. All organic matter had been removed, leaving a bare mineral soil surface. White spruce, black spruce, and birch were seeded in October 1971. Birch plots were seeded with 300 seeds (germination 65 percent), white and black spruce with 200 seeds (germination 75 and 65 percent, respectively). Observations were made weekly until the first seedling was observed on June 21, 1972; seedling counts were repeated on July 21 and August 20.

The experiment consisted of three study blocks. Within each block, each species was replicated three times. Each replication consisted of a 1-m^2 plot; within this plot two 25-cm-diameter circular plots were located. One of these plots was covered with hardware cloth; the other was unprotected.

Germination of birch exhibited a similar pattern on both aspects; i.e., a peak in mid-June to late June with relatively little additional germination. Both white and black spruce exhibited a similar response on the north slope; however, peak activity was later than that observed for birch. On the south slope, spruce germination did not exhibit a distinct peak (fig. 18). These differences in response of species to aspect are believed related to hot, dry surface conditions which occurred on the south slope in late June (Clautice 1974).

At the fireline site, no germination was observed before June 14 on either the protected or unprotected plots. During the week prior to June 21, approximately 80 percent of the annual germination occurred in the protected plots. In the unprotected plots fewer germinants were observed; however, a higher percentage (90) were from the period prior to June 21 (table 22). The relatively low number of seedlings produced indicate that loss of seed on unprotected plots was significant. Survival of germinants through early September was similar on north and south slopes. Survival of birch was lowest, followed by white spruce and black spruce. Percentage of survival, however, depended on the germination date. June germinants exhibited poor survival on the south slope; survival of July and August germinants was generally higher. On the north slope, first growing season survival was highest for June and August germinants (fig. 19). On the fireline sites, seedlings germinating prior to June 21 contributed the majority of the seedlings to the August 21 population (table 22).

Moisture and temperature are two important factors regulating seed germination. Average daily maximum and minimum mineral soil surface temperatures during peak birch germination on the south slope were 7°C and 24°C; on the north slope, 4°C and 17°C. During the hottest period of the summer (June 27 to July 11), when mortality reached a maximum on the south slope, average daily maximum surface temperatures were 29°C on mineral soil, 39°C on

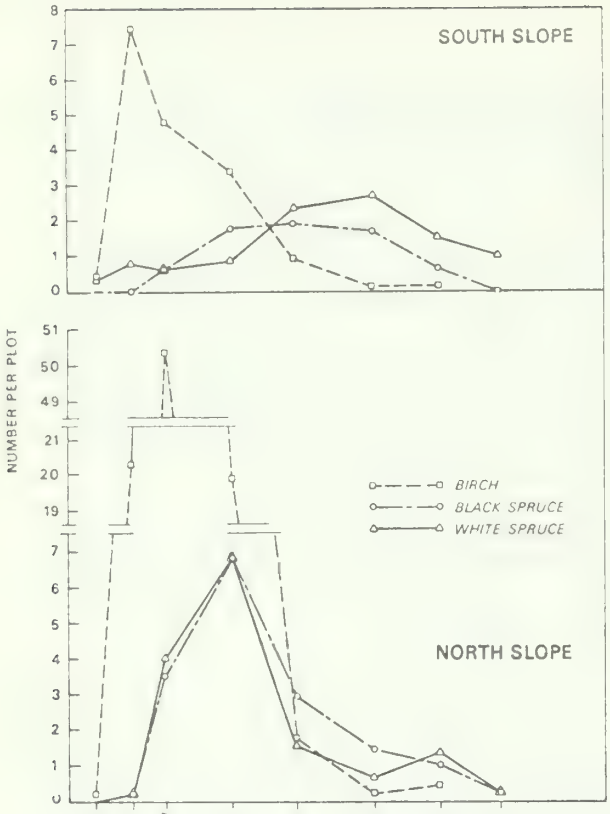


Figure 18.--Weekly germination of seeded birch, black spruce, and white spruce on north and south slopes 1 year after fire (1972).

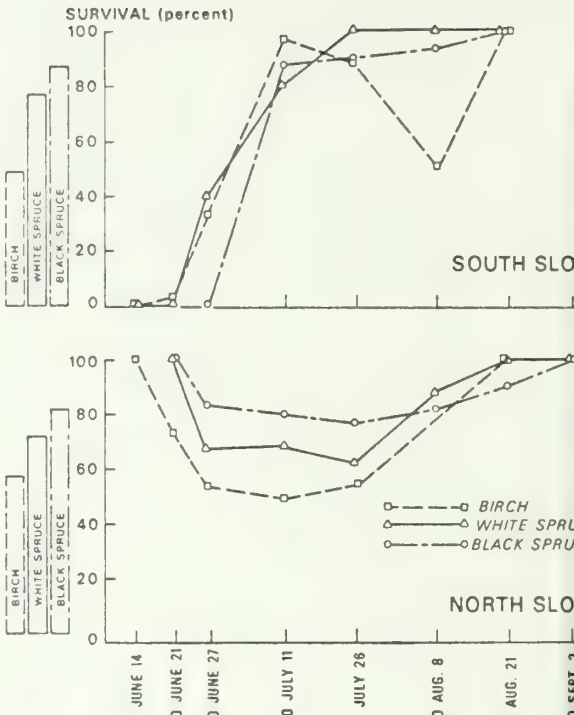


Figure 19.--Percent of birch, white spruce, and black spruce seedlings surviving to September by date of germination (1972).

Table 22--Germination and survival of birch and white and black spruce seedlings on mineral soil on 3 dates during the 2d growing season after a wildfire, Wickersham Dome study area

Species and number	June 21		July 21				August 21				
	Protected[1/]	Unprotected	Surviving June 21 seedlings[2/]	New seedlings		Total[2/]	June 21 seedlings[2/]	July 21 seedlings[2/]	New seedlings		Total[2/]
				Protected	Unprotected				Protected	Unprotected	
Birch:											
1	0	3.5	0 / 1.0	0.7	0	0.7/ 1.0	0 / 1.0	0 /0	0.3	0	0.3/ 1.0
2	5.0	4.0	2.7/ 2.3	.7	0	3.4/ 2.3	1.2/ 2.3	.7/0	0	0	1.9/ 2.3
3	3.7	1.0	3.7/ .3	.3	.3	4.0/ .6	3.3/ .3	.3/ .3	0	0	3.6/ .6
White spruce:											
1	25.3	3.0	24.3/ 1.7	17.3	.7	41.6/ 2.4	22.3/ 1	11.3/ .3	0	0	33.6/ 1.3
2	28.7	.3	23.7/ .3	7.7	0	31.4/ .3	21.0/ .3	5.0/0	0	.3	26.0/ .3
3	35.3	25.0	22.3/22.3	2.0	0	24.3/22.7	18.7/19.7	1.3/ .3	0	0	20.0/20.0
Black spruce:											
1	3.7	0	3.0/ 0	.7	0	3.7/ 0	1.3/ 0	0 /0	0	.3	1.3/ .3
2	2.0	0	1.3/ 0	1.7	0	3.0/ .3	1.3/ 0	0 /0	1.3	0	2.6/ 0
3	11.0	2.0	8.0/ 1.3	1.0	0	9.0/ 1.3	6.3/ 1.3	.6/0	0	.3	6.9/ 1.6

[1/] Seeded area protected by hardware cloth.

[2/] Protected/unprotected seedlings.

ash, and 41°C on charred moss. Absolute maximum temperatures recorded during this period were 41°C, 68°C, and 77°C on mineral soil, ash, and charred moss, respectively. Soil moisture was not measured; however, mineral soil had a consistently moist surface on the north slope.

Natural revegetation.--Significant differences existed between surface condition, species composition, and major type of reproduction between the north and south slopes (tables 23 and 24). A chi-square test of the differences in the density values of the June species among the surfaces showed the surface classification to be significant at the 0.05 level. Surfaces with the largest amount of similar vegetation were "flat charred moss" and the more deeply burned "convoluted burned moss." Both these conditions were included in the general moderately burned category.

Effects of Fire on Arthropod Distribution[20]

The sampling of arthropod populations in 1972 and 1973 was limited to 10 pit traps in the burned and the unburned control areas. The pit traps were checked weekly for 9 weeks, and the trapped arthropods were collected and stored in 80 percent ethanol. The specimens were separated and the data analyzed according to five major categories: spiders, Collembola, mites, Coleoptera, and other arthropods.

The total number of arthropods collected in 1973 was significantly lower than similar collections from 1972 (table 25). The unburned control and burned areas produced 44 and 23 percent fewer arthropods, respectively, in 1973. In both years, however, the burned areas produced more specimens than the unburned control areas, which indicates either a higher population of arthropods or higher arthropod activity in the burned areas and therefore a greater chance of capture.

There was a significant decrease in the percentage of mites (46), Collembola (43), and Coleoptera (72) captured in 1973 and no significant change in the "other arthropods" category. The number of spiders captured in burned areas in 1973 was 1.3 times higher than in 1972, and in 1973 spider numbers were 3.0 times higher in the burned area than in the unburned control. The decrease in most arthropod populations in burned areas compared with the increase in spider populations can be attributed to predation by spiders. Spider predation would be higher in the burned area because of sparse ground vegetation which offers protection to prey species.

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[20]This section was prepared by R. C. Beckwith, Principal Insect Ecologist, Forestry Sciences Laboratory, Corvallis, Oregon, and R. A. Werner, Research Entomologist, Institute of Northern Forestry, Fairbanks, Alaska; both men are with USDA Forest Service, Pacific Northwest Forest and Range Experiment Station.

Table 23--Density of vegetation on 4 burned surfaces on the south slope during the 2d growing season after the Wickersham Dome fire

Species	Origin of reproduction[1]	Month	Density				Total area	
			Lightly burned moss[2]	Flat charred moss[2]	Convoluted burned moss[4]	Ash[5]	Density	Frequency
			- - - - - -Stems per square meter- - - - - -					Percent
Alnus	v	June	1.56	0.05	0	0	0.31	6
crispa		Sept.	1.56	.99	0	0	.89	12
Betula	v	June	0	0	7.58	0	.61	3
papyrifera		Sept.	0	0	7.95	0	.64	3
Calamagrostis	s	June	10.75	7.70	0	0	6.37	41
canadensis		Sept.	24.09	17.96	.38	0	14.45	44
Corydalis	s	June	.52	.[illegible]	9.85	5.27	1.88	32
sempervirens		Sept.	1.39	1.04	12.88	6.09	2.79	47
Epilobium	s	June	.17	.21	0	.61	.24	15
angustifolium		Sept.	.17	.[illegible]	0	.81	.42	18
Rosa	v	June	0	.10	0	0	.06	3
acicularis		Sept.	0	.42	0	0	.24	9
Rubus	s	June	0	.05	0	3.65	.58	21
idaeus		Sept.	.35	.10	0	3.04	.58	32

[1] v = vegetation; s = seed.

[2] Only upper surface of moss charred.

[3] Deeper charring in moss layer (moderately burned).

[4] Variable burning in moss layer (moderately burned).

[5] Moss layer consumed, only ash remaining on surface of mineral soil (heavily burned).

Table 24--Density of vegetation on 7 burned surfaces on the north slope during the 2d growing season after the Wickersham Dome fire

Species	Origin of reproduction[1]	Month	Density							Total area	
			Living moss[2]	Dead moss[3]	Lightly burned moss[4]	Flat charred moss[5]	Convoluted burned moss[6]	Ash[7]	Mineral soil[8]	Density	Frequency
			- - - - - - - - - - - - -Stems per square meter- - - - - - - - - - - - -								Percent
Calamagrostis	v	June	0	4.12	3.04	4.85	6.36	1.23	0	3.00	38
canadensis		Sept.	0	6.18	4.15	8.44	7.63	1.23	0	4.31	47
Epilobium	s	June	0	0	0	0	0	0	0	0	0
angustifolium		Sept.	0	0	.18	0	0	0	0	.03	3
Equisetum	v	June	17.11	13.92	19.83	22.89	23.41	37.42	18.64	21.74	97
pratense		Sept.	18.42	18.04	23.34	28.28	25.45	43.56	28.81	25.97	97
Ledum	v	June	38.16	15.46	2.49	0	0	0	0	2.77	31
groenlandicum		Sept.	38.16	23.71	4.70	.09	.51	0	0	4.16	38
Marchantia	s	June	0	0	0	0	0	0	6.80	.12	3
polymorpha		Sept.	0	0	0	0	0	0	16.90	.36	3
Oxycoccus	v	June	81.58	0	0	0	0	0	0	2.00	3
microcarpus		Sept.	78.95	10.82	0	0	0	0	0	2.61	6
Picea	s	June	1.32	0	0	0	0	0	0	.03	3
mariana		Sept.	1.32	0	0	0	0	0	0	.03	3
Polygonum	v	June	0	0	.18	0	0	0	0	.06	3
alaskanum		Sept.	0	0	.18	0	0	0	0	.06	3
Polytrichum sp.	s	June	0	0	0	0	0	0	0	0	0
		Sept.	0	0	0	.36	.25	3.68	0	.35	9
Rosa	v	June	0	0	0	0	0	0	0	0	0
acicularis		Sept.	0	0	0	.36	0	0	0	.13	3
Rubus	v	June	3.95	2.06	5.81	.63	.25	0	0	3.52	41
chamaemorus		Sept.	3.95	5.15	8.12	1.89	.25	0	0	3.97	56
Rubus	s	June	0	0	0	0	0	.61	0	.03	3
idaeus		Sept.	0	0	0	0	0	.61	3.39	.10	6
Spiraea	v	June	0	0	.28	0	0	0	0	.10	3
beauverdiana		Sept.	0	0	.37	0	0	0	0	.13	3
Vaccinium	v	June	0	1.03	.18	0	0	0	0	.13	6
uliginosum		Sept.	0	1.03	.18	0	0	0	0	.13	6
Vaccinium	v	June	0	161.34	10.70	.18	0	0	0	3.90	41
vitis-idaea		Sept.	0	162.89	10.88	.18	0	0	0	4.06	41

[1] v = vegetation; s = seed.

[2] Unburned.

[3] Moss scorched and killed by heat.

[4] Only upper surface of moss charred.

[5] Deeper charring in moss layer (moderately burned).

[6] Variable burning in moss layer (moderately burned).

[7] Only ash remaining on surface of mineral soils (heavily burned).

[8] Mineral soil exposed by fireline construction.

[9] Expressed in percent cover.

Table 25--Numbers of arthropods collected from pit traps, Wickersham Dome, 1 and 2 years after a 1971 wildfire[1/]

Year and area	Spiders	Mites	Collembola	Coleoptera	Other arthropods	Total
1972:						
Unburned control	320	178	1,142	53	454	2,147
Heavy burn	557	701	866	113	382	2,619
1973:						
Unburned control	249	167	500	9	270	1,195
Heavy burn	736	381	494	32	286	2,029

[1/] Based on 9 similar collection dates for each year.

Numeric Response of Microtine Rodents After Fire[21]

Postfire population response of the northern red-backed vole (*Clethrionomys rutilus*) and the tundra vole (*Microtus oeconomus*) was investigated during a yearlong live trapping from June 2, 1972, through June 18, 1973, in the severely burned area and adjacent unburned control area of black spruce taiga at the Wickersham ridgetop site (plots BS-3H and BS-3C).

These areas were trapped again in the fall of 1973 and the subsequent summers of 1974, 1975, and 1976. The density information summarized here pertains to the 1972-73 year and the summer of 1974. Other aspects of this work have been presented by West (1977) and a more exhaustive treatment in a Ph.D. thesis (West 1979).

All population measurements were taken on two parallel live-trapping grids, one in the burned area and one in the unburned control area. Both grids consisted of 96 large folding aluminum live traps, spaced at 10-m intervals in an 80- by 120-m configuration along the ridgetop. With a 5-m boundary strip assumed, this spacing produced a trapping area of 0.96 ha. The traps were baited with rolled oats and operated during the night hours (about 10 p.m. to 8 a.m.) for 3 consecutive days every 2 weeks. Basic information collected at each capture included weight, sex, point of capture, and reproductive condition. Toes of voles were clipped for individual recognition.

The overall trends in size of populations for northern red-backed vole and tundra vole for 1972-74 are shown in figure 20. The most striking feature of the population density of northern red-backed vole is its pronounced annual cycle. Breeding seasons

[21] This section was prepared by S. D. West, graduate student, Museum of Vertebrate Zoology, University of California, Berkeley.

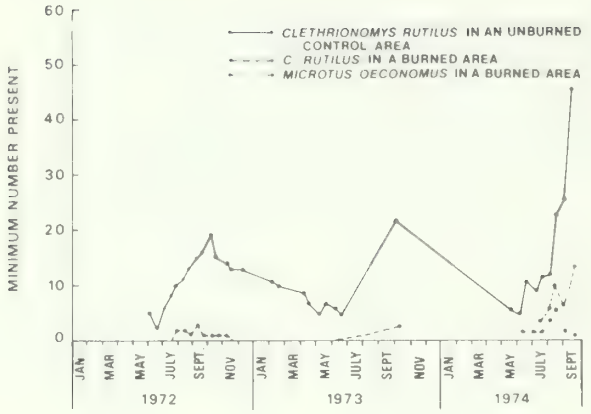


Figure 20.--Population trends for the northern red-backed vole and the tundra vole in an area burned in 1971 and an adjacent unburned control area.

are periods of consistent increase, characteristic of populations with overlapping generations. These peak densities are intermediate in terms of the peak densities observed for northern red-backed vole in interior Alaska white spruce forests (Pruitt 1957). The breeding seasons for northern red-backed voles extended from May to September; most activity was concentrated in June, July, and August. The adult sex ratio in the population was approximately one to one.

In the unburned control area, the spring and fall density in both 1972 and 1973 were similar. The fall 1973 trapping period probably caught all but two or three voles that were on the grid at that time. The slightly larger spring 1974 population might indicate improved winter survival compared with survival in 1973, or that the spring 1974 immigration rate was higher than 1973, resulting in a larger population in June 1974. A high recapture rate during the fall 1973 trapping periods and the concomitant absence of reproductively active voles suggest that most voles on the study area had been marked by the 1st week in October. Only 1 vole out of 22 marked in the fall of 1973 was captured the next spring, however, which indicates an influx of unmarked adults. This pattern was also seen in spring 1973 but to a lesser extent (West 1974).

On a seasonal basis, mortality for northern red-backed vole was highest in the fall, lowest in winter, and intermediate in summer. Spring rates were difficult to determine because of small size of population.

The substantial increase in density in fall 1974 was not due to an extended breeding season relative to the preceding 2 years. The absence of pregnant, lactating, or estrous females and the absence of scrotal males indicated that reproduction had ceased in both years by the end of September. In fact, the number of reproductively active females was similar from July through September each year. The difference in density was most likely due to increased survival of juveniles in late August and September. The density in 1975 was nearly identical to that of 1974, and the density in 1976 was about the same as 1972 and 1973. Minimum annual densities have all been fewer than 10 voles, lending force

to the arguments of Whitney (1976) that the northern red-backed vole is not cycling in the classic microtine fashion in interior Alaska. The annual cycle of maximum density appears to be determined by the survival of juveniles from the fall generation.

In 1972, activity of red-backed voles in the heavily burned area was very low over the first postfire growing season and was confined to the late summer-early winter period from late July to early November. Only seven voles were caught in the burned area during that time; 2 of these accounted for 12 of the 18 total captures in the burned area, and these 2 were caught in the unburned control area as well. The fall 1973 trapping indicated essentially the same density as that of the previous fall. None of the three voles known to be alive in fall 1973 was recaptured; the spring 1974 population consisted of immigrants. In 1973 the red-backed voles abandoned the burned area as they had the preceding winter. No red-backed voles were caught in the burn until the latter part of July 1974, when the population in the burned area increased substantially. Both postpartum females and very young voles were caught, which indicated breeding on the burned area. Voles overwintered in the burned area for the first time in 1974.

The tundra vole (*Microtus oeconomus*) was captured only one time (August 1972) in the unburned control area and was not captured in the burned area until the spring of 1974. Observations in the burned area immediately after snowmelt in 1974 indicated that tundra voles were present prior to the thaw. Several runways and burrows were found, primarily in moist, low-lying zones and in root tangles. These animals could have been either overwintering animals not caught in fall 1973 or, more likely, immigrants during early spring 1974. As shown in figure 20, the tundra vole population increased until mid-August and declined thereafter. The possibility exists that the decline was due to the increasing population of red-backed voles present on the burned area. As plant succession proceeds on the burned area, the vegetational composition will more closely resemble the habitat requirements of the tundra vole, and a resident population should become established. Trapping in several successional areas where time since last fire is known indicates that peak tundra vole densities at Wickersham Dome can be expected in 4-12 years from 1974, depending on the rate of plant succession.

Habitat Utilization By Snowshoe Hares In Burned and Unburned Black Spruce Communities[22]

The impact of snowshoe hares on secondary succession after fire has not been determined in the taiga of interior Alaska.

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[22]This section was prepared by J. O. Wolff, Research Associate, Museum of Vertebrate Zoology, University of California, Berkeley, and Institute of Northern Forestry, Fairbanks, Alaska; C. T. Cushwa, Wildlife Biologist, Forest Environment Research, USDA Forest Service, Washington, D.C.; and K. P. Burnham, Biometrician, Western Energy and Land Use Team, U.S. Fish and Wildlife Service, Fort Collins, Colorado.

The 1971 fire at Wickersham Dome and the adjacent, unburned 70-year-old black spruce stand presented an opportunity to study habitat utilization by snowshoe hares in the two communities. The major objectives of this portion of the study were to compare population densities of snowshoe hares in the burned and unburned control stands and to relate these to availability of food and cover. Food habits and browse intensities by snowshoe hares were also recorded to determine the impact of snowshoe hares on forest regeneration and plant succession. Wolff (1977) reported on the snowshoe hare project at the Wickersham Dome study area.

In summer 1972, two 40-ha grids of live-traps were established, one in the burned area and one in the adjacent, unburned control area. Each grid consisted of 100 traps in a 10 by 10 array with 60 m between any two traps. In 1974, each grid was reduced to an 8 by 10 array of traps encompassing an effective area of 34 ha. Single-door traps of wire were made according to the method described by Cushwa and Burnham (1974) and were baited with alfalfa cubes. Trapping periods varied from 6 to 10 consecutive days and were initiated in November 1972. Spring trapping was conducted in April when the hares were still on a winter diet. The ears of captured hares were tagged, and the hares were weighed and sexed prior to release. Individual traps were numbered to identify exact locations of captures for movement calculations. Vegetation was sampled in both areas to determine densities of trees and shrubs and percent ground cover of low shrubs, herbs, mosses, and lichens.

In the Wickersham Dome fire, hares consumed virtually all the postfire willow sprouts during September following the July burn (fig. 21). During the winter of 1971-72, they consumed charred bark of black spruce, aspen, and birch (fig. 22). The second winter after the fire (1972-73), hares consumed all the aspen sucker regrowth in several stands (fig. 23). From 1971 to 1973, 100 percent of the available hardwood browse (willow, alder, and aspen) was consumed in the unburned control and a 200-m strip of the burned area paralleling the unburned area (table 26). From 1973 to 1976, browse intensity by snowshoe hares decreased concurrently with an overall decline in the hare population.

The high intensities of browsing on willow and aspen for 2 years after the fire stimulated lateral branching which increased vegetative growth. Current annual growth was removed each winter, but the long-term effects were increased production of aboveground biomass (Wolff 1978a).

The results from live-trapping at Wickersham Dome from 1972 to 1976 are shown in table 27 and illustrated in figure 24. We used the Schnabel and Lincoln indices with a 95-percent confidence interval to estimate populations (Giles 1969).

In the fall of 1972, 74 hares were live trapped, tagged, and released in the unburned control; only 3 hares were caught in the burned area. A population estimate for the unburned control for 1971 would be about 200 animals (Ernest 1974). By April 1973 the population of hares in the burned area had increased to 15, 13 of



Figure 21.--Hares consumed virtually all the willow sprout regrowth during September after the July wildfire.



Figure 22.--Evidence of browsing by snowshoe hares on charred black spruce at the 1971 Wickersham Dome fire site.



Figure 23.--Consumption of aspen regrowth by hares the second winter after the 1971 Wickersham Dome fire.

Table 26--Intensity of browsing by snowshoe hares at the Wickersham Dome study site for 5 years after a 1971 wildfire[1/]

Area	1971-72	1972-73	1973-74	1974-75	1975-76
			-Percent-		
Burned	100	100	3 ± 1.7	0	0
Unburned control	100	100	45 ± 3.3	4 ± 2.3	1 ± 1.2

[1/] Plus or minus signs indicate standard error of the mean.

Table 27--Population estimates of snowshoe hares for the Wickersham Dome unburned control, based on data of recaptured, marked hares[1/]

Trapping period	Total captured	Total recaptured	Total marked animals	Population estimate			
				Schnabel[2/]		Lincoln[2/]	
	----Number----			Average	95-percent confidence interval	Average	95-percent confidence interval
Nov. 1972	164	90	74	85	69-105	78	52-112
Apr. 1973	221	152	69	67	57-79	70	46-102
Apr. 1974	117	74	43	42	33-52	45	29-65
July 1974	44	21	22	27	16-41	29	6-108
Sept. 1974	19	9	10	12	5-23	10	1-95
Nov. 1974	12	2	11	26	4-147	24	2-468
Apr. 1975	5	1	4	8	1-156	6	0-117
Aug. 1975	12	8	4	4	2-9	4	1-15
Nov. 1975	4	2	4	5	0-14	5	0-39
Apr. 1976	17	10	9	8	4-20	7	3-16
Aug. 1976	54	29	21	20	14-27	23	17-29

[1/]Population estimates are number of hares per 34 hectares.

[2/]Giles (1969).

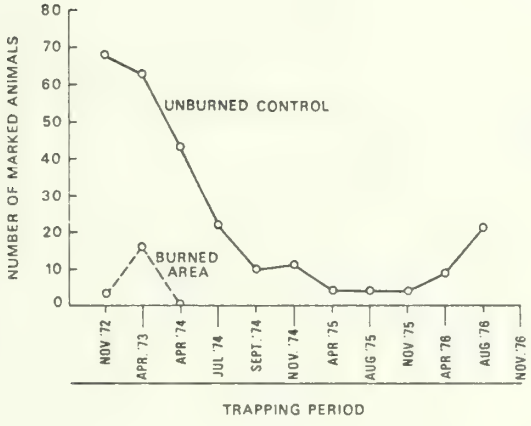


Figure 24.--Number of marked snowshoe hares caught in the burned area and the unburned control at Wickersham Dome after a 1971 wildfire, 1972-76.

which were marked transients from the unburned control; the number of animals caught in the control was 69, 31 of which were recaptured from the fall population. Field observations revealed that hardwood browse had become limited in the unburned control, and hares were forced to leave the protection of the mature forest and enter the open burn in search of food. Survival rates of marked animals were much greater in the dense black spruce stand than in the burned area or the more open portions of the spruce stand.

One year later, in the spring of 1974, only 43 hares were tagged in a 7-day trapping period in the unburned control and 1 in the burned area. Hares had been seen crossing from the control into the burned area, but there appeared to be no permanent residents in the burned area. Quantitative measurements revealed that there was enough hardwood browse in the unburned control to maintain a population at that level. Browse intensity in the burned area was only 3 percent, whereas in the unburned control about 45 per-

cent of the available browse was consumed. By July 1974, only 22 hares were caught in the unburned control; by November, only 11. No hares were caught in the burned area from 1974 to 1976. The low number of hares marked in November 1975 was thought to be an underestimate caused by a change in trapping procedures. The population reached a low of 4 hares in April 1975 but increased to 21 by August 1976.

The population decreased from a high of six hares/ha in the fall of 1971 to a low of 0.12 hare/ha in April 1975. The decline was gradual but continuous through the summer reproductive seasons as well as during the winter. The decline may have been initiated by decreased quantity and quality of forage during the peak population densities from 1971 to 1973, which resulted in reduced physiological fitness and eventual starvation. The continued decline from 1973 to 1975 was probably due to increased rates of predation which increased hare mortality (Wolff 1977).

Food habits of snowshoe hares were determined by microscopic analysis of stomach contents (Wolff 1978b). Blueberry, lowbush cranberry, fireweed, and horsetail made up 47 percent of the spring diet; and leaves of birch, willow, rose, and other deciduous shrubs made up 76 percent of the summer diet (fig. 25). Trap results indicate that hares migrate seasonally in response to this change in diet. In the summer, hares prefer open areas where blueberry, lowbush cranberry, and other herbaceous plants are more plentiful. During the winter when the herbs and low shrubs are covered with snow, hares move back into the dense black spruce thickets where they feed on spruce needles and bark and twigs of birch, willow, and alder.

Populations of snowshoe hares in Alaska and throughout the boreal forests of North America appear to fluctuate on a 10-year cycle. Densities may show a 60-fold difference from high to low years and range from 800 to 12 hares/km^2. The study of snowshoe

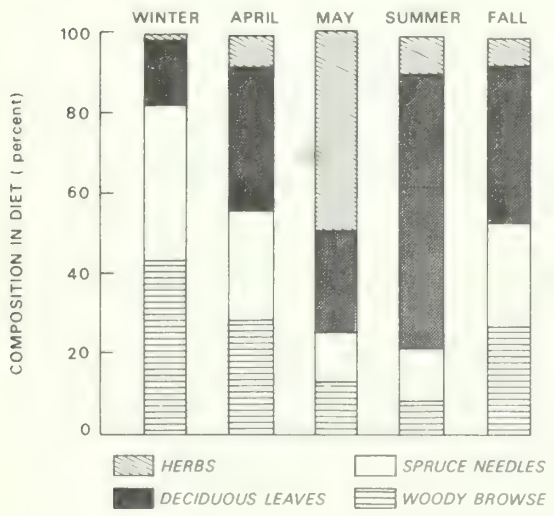


Figure 25.--Diet of snowshoe hares at different times of the year.

hares at Wickersham Dome was conducted during the peak and declining phases of the cycle. When the population densities were low, hares remained in dense black spruce or willow-alder thickets where food and cover were plentiful. During high densities when hares exceeded their overwinter food supply in preferred habitat (1971 through 1973), they invaded more open and recently burned areas to forage on new growth of woody browse plants. During these high densities, hares occupied all suitable habitat, and browse intensity reached 100 percent. Excessive browsing by hares had an adverse effect on regeneration of woody plants from 1971 through 1973. Long-term effects of excessive browsing may, however, result in increased production of woody browse because of lateral branching of browsed stems. In conclusion, we feel that hares have the greatest impact on regeneration of trees and woody shrubs for only a 2- to 3-year period in a 10-year cycle.

SUMMARY[23]

The Wickersham Dome fire occurred in late June 1971 and burned over approximately 6 300 ha. The fire, which was typical of interior Alaska wildfires, was brought under control after tractor construction of 113 km of firelines and aerial application of some 242 000 liters of fire retardant. Before the fire, the area was mostly covered with black spruce stands, ranging in age from 50 to 125 years. The forest floor was made up of a continuous mantle of mosses, principally feather mosses with some *Sphagnum*. Stands of quaking aspen occurred on some slopes and were characterized by a striking decrease in moss cover. The area is one of relatively gentle relief, with rounded ridges and elevations ranging from 210 to 980 m. Soils are silt loam and formed in wind-deposited loess. Ridges and upper south slopes are free of permafrost; in other locations, soils generally have a permafrost table within 40 to 50 cm of the surface.

Shortly after the fire was controlled, eight plots were established in black spruce areas for intensive study of the ecological effects of the fire. These plots were arranged in three sets located on the ridgetop and middle and lower slopes. Two plot sets consisted of an unburned control, a lightly burned stand and a heavily burned stand. The other set (on the ridgetop) contained only a heavily burned stand and an unburned control. Three additional plots were established 1 year after the fire (June 1972)--a heavily burned stand and an unburned control in aspen, plus another unburned control in black spruce.

Although certain portions of this study are continuing, results reported here are mainly for the first 3 years after the fire (1972-74).

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[23]This section was prepared by C. T. Dyrness, Supervisory Soil Scientist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Fairbanks, Alaska.

Examination of soil after the fire indicated that moist lower forest floor layers had minimized the impact of the fire on the soil. Other than in firelines, patches of bare mineral soil were rare, even in heavily burned areas. Measurements of burned forest floor thickness indicated greatest fire effects occurred where forest floors were thickest; starting with an unburned thickness of 28.7 cm, average reductions were 10.3 cm for heavily burned areas and 5.7 cm for lightly burned areas. In other words, even in heavily burned areas an average of almost two-thirds of the forest floor remained after burning. Weight and bulk density of forest floor samples were also determined; however, no statistically significant effect of the fire could be determined. In view of the rather shallow depth of burning in the forest floor, it is perhaps not surprising that the burning had no discernable effect on chemical properties of the mineral soil. Cation exchange capacity, pH, exchangeable Ca, Mg, and K, available P, and total N were determined on samples from the surface 15 cm of mineral soil in burned and unburned areas, but there were no significant differences between the areas.

The reduction of forest floor thickness and blackening of the surface by fire causes higher soil temperatures. Most studies have indicated that surface soils which have been recently burned warm up more quickly at the beginning of the growing season and are substantially warmer than unburned soils. This relationship also proved true in the present study; 1 year after the fire, the soil temperature at a depth of 10 cm reached a maximum of 10.5°C on July 20 in a burned area. In the unburned control, the maximum temperature was only 6°C, and the peak was delayed until September 13.

In interior Alaska one of the most important consequences of increases in soil temperature caused by fire is stepped up permafrost melting. Such thawing substantially increases the amount of available soil nutrients and soil water. On the Wickersham Dome fire site, change in the rate of thawing was particularly dramatic; 1 year after the fire, the active layer was 62 cm thick in the burned area and only 42 cm in the unburned control. By the 3d year, the active layer had increased to 84 cm in the burned area and 47 cm in the unburned control. On firelines, where virtually all surface insulation had been removed, the rate of permafrost drop was almost doubled; 3 years after the fire, the active layer in the firelines was 132 cm thick.

Despite substantial changes in the microclimate caused by fire, especially in and around the forest floor, studies of aboveground macroclimatic parameters did not disclose measurable differences between burned and unburned areas. For example, patterns of snow accumulation and snowmelt were not substantially different in a burned area than in an unburned area. Likewise, standard measurements of air temperature did not disclose a difference between burned and unburned areas.

Unfortunately, little work has been done in interior Alaska on the effects of wildfire and fire suppression on quality of stream water. There are speculations that increases in erosion and runoff caused by fire are at a minimum in northern areas,

but data to back this up are lacking. To obtain an indication of the effects of the Wickersham Dome fire on streams, we sampled Washington Creek both above and below the fire on the day the fire was controlled, 1 week after control, and 2 weeks after. The day the fire was controlled, suspended sediment content of the stream was about 300-500 mg/liter. After the Bureau of Land Management constructed water bars on the firelines, the sediment content dropped to a maximum value of 19 mg/liter 1 week after control. A small increase in concentration of phosphate in the stream water was measured after applications of retardants; however, concentrations of nitrogen were the same above and below the burned area.

Development of vegetation after the fire was, as would be expected, closely tied to severity of the fire. On a lightly burned black spruce plot 40 percent of the ground vegetative cover was still alive after the fire. This increased to a total of 70 percent cover 3 years after the fire (August 1974). Considerable amounts of mosses and *Cladonia* lichens survived the fire and greatly contributed to its rapid postfire recovery. Although many black spruce seedlings and saplings were alive after the fire, the majority of these died during the subsequent 3 years, leaving only 61/ha. Spruce seedlings, however, germinated in large numbers; nearly 40,000/ha were recorded in 1974.

In contrast, recovery of vegetation on heavily burned black spruce plots has been much slower. No climax mosses and lichens survived the fire; consequently, moss and liverwort cover was low after 3 years and was made up exclusively of the invaders *Marchantia polymorpha* and *Ceratodon purpurea*. Herbaceous cover recovered at a faster rate and reached about 15-20 percent after 3 years--substantially higher than that in the unburned control. Principal herbaceous species in these early postfire years were *Equisetum sylvaticum* and *Epilobium angustifolium*, both present in the unburned control. Response of shrubs to fire on heavily burned plots has been mixed. On one plot, *Salix scouleriana* sprouted rapidly after the fire and by the 3d year had three times the basal area of the unburned control. In other areas, however, sprouting of shrubs was less vigorous; after 3 years, densities were still appreciably lower than on the unburned control.

One of the most significant findings of our studies of revegetation was that very few of the plant species appearing soon after a fire are invaders. The great majority are species that were present in the prefire stand and reproduce vegetatively from underground plant parts surviving the fire. This process of vegetative reproduction was especially striking in the heavily burned aspen stand. During the 1st year after the fire, there were nearly 200,000 aspen shoots per hectare. *Rosa acicularis* also greatly increased its cover after the fire by means of stem and root shoots. Because most of these underground parts that are active in postfire reproduction are located in the organic forest floor layers, depth of burning becomes of overwhelming importance in controlling the nature of early successional stages. With increasing depths of burn, more and more of these structures will

be eliminated until, with bare mineral soil, only sparse vascular plant cover will be present during the 1st year after burning.

Some workers have speculated that, as a result of warmer sites and accelerated nutrient cycling, early stages of postfire succession in the Alaska taiga would be marked by increases in primary productivity. To test this assumption, we undertook a limited sampling program of annual biomass and litter fall at the Wickersham Dome study site. Biomass at the end of the 3d year after the fire was extremely variable, ranging from a low of 33 g/m^2 on a heavily burned black spruce plot to a high of 804 g/m^2 on the heavily burned aspen plot. Although approximately 60 percent of the top figure was contributed by aspen sprouts, *Ceratodon*, *Marchantia*, *Epilobium*, and *Calamagrostis* also had sizable amounts of biomass. Despite the fact that the aspen sprouts were heavily browsed, they continued to grow well and the browsing apparently encouraged the development of lateral branches. This very high production of available browse illustrates the possible value of fire in the production of wildlife habitat.

To fully understand the effects of fire on nutrient cycling, we must measure both litter fall and rates of litter decomposition. In the burned black spruce plots, litter fall originated primarily from standing dead trees and willows. Litter fall in lightly burned plots was heaviest the 2d year after the fire when it averaged about 20 g/m^2 (versus 10 g/m^2 in the unburned control, and 7 g/m^2 in heavily burned plots). During the 3d year after burning, litter fall decreased in both burned black spruce areas. As would be expected, litter production in the burned aspen plot was very high (118 g/m^2 per year) because of abundant sprouts.

Rates of litter decomposition were estimated from contents of litterbags placed on the forest floor in both unburned and heavily burned black spruce stands. The nylon mesh bags contained three types of litter: black spruce needles and blueberry and Labrador-tea leaves. Preliminary results indicated that rates of decomposition were the same in burned and unburned stands. Black spruce needles and Labrador-tea leaves had about 31-percent weight loss after 2 years; blueberry leaves lost 37 percent of their weight.

Black spruce is a species ideally suited to reseed an area disturbed by fire. Since its cones are semiserotinus, the fire-killed tree can continue to release considerable quantities of seed for years. To compare quantity and quality of seed from burned sites with that of seed from unburned sites, we followed seed dispersal and seedling establishment in lightly and heavily burned stands and an unburned control. During the 1st year after the fire, black spruce seed fall in the burned plots (average of 331/m^2) was almost four times as great as that in the unburned control (85/m^2). Despite more seed from burned trees, timing of seed dispersal was the same in burned and unburned stands. Peak dispersal occurred in midsummer during periods of high temperature and low humidity. Seed quality was apparently adversely affected by high temperatures. Testing of seed dispersed the 1st year after the fire showed higher percentages of germination in the unburned control and lightly burned stands than in the heavily burned areas.

Also, the germination capacity of seed from fire-killed trees appeared to decrease with time. Germination for filled seeds averaged 90, 65, and 32 percent for seeds collected from burned black spruce trees 1, 2, and 3 years after the fire, respectively. Even if only germinable seed are considered, seedling establishment appears to be difficult on burned sites. Counts indicated that on burned plots only 1 percent of germinable seeds actually developed into established seedlings.

To more closely follow trends in germination and establishment of tree seedlings in recently burned areas, we carried out an artificial seeding experiment the summer of 1972. Black spruce, white spruce, and paper birch seeds were sown in early June on plots having a north and south aspect. Birch germination reached a peak in mid-June to late June on both north- and south-facing slopes. Germination of both white and black spruce seed peaked in late June on the north slope, but the germination period was more diffuse and spread out on the south slope. Seedling mortality occurred earlier on the south slope plots and appeared to be mainly caused by high temperatures and desiccation. Factors causing seedling mortality on the north slope were browsing, damping-off, and smothering by competing vegetation. By September, however, the proportion of surviving seedlings was approximately the same on both aspects. Percentage of seedling survival was highest for black spruce, second for white spruce, and lowest for paper birch.

Studies of animals after the fire focused on insects, microtine rodents, and snowshoe hares. Numbers of spiders, Collembola, mites, Coleoptera, and other arthropods were followed in burned and unburned areas during the summers of 1972 and 1973. During both years, the burned area supplied more captured specimens than the unburned. It does not, however, necessarily follow that insect numbers were higher in the burned area; it might simply indicate a higher degree of arthropod activity. The numbers captured in all categories except spiders decreased appreciably in 1973. This decline in numbers in most arthropod populations was attributed to predation by spiders.

Voles were live trapped in a heavily burned area and an adjacent unburned control for the first 3 years after the fire. Despite the presence of numerous northern red-backed voles in the unburned area, its activity in the burned area was very low and strictly confined to the period from late July to early November in 1972 and 1973. Starting in July 1974, the population of red-backed voles in the burned area increased substantially and some overwintered there for the first time in 1974-75. The tundra vole was apparently very rare in the unburned black spruce stands where only one animal was ever caught. Tundra voles, however, entered the burned area in early spring of 1974, and the population increased until mid-August when a moderate decline set in. By the 3d year after the fire, both red-backed voles and tundra voles had apparently established resident populations in the burned area.

The fire coincided with the high point in the 10-year population cycle of the snowshoe hare. Consequently, in the fall of 1971, the hares consumed large quantities of willow sprouts that were already

coming up in the burned area. During the winter, when the supply of sprouts was exhausted, the hares fed on charred bark. The population continued at high levels until 1973 and consumed all the available hardwood browse in the unburned control and for at least 200 m into the burned area. In 1974, density of hares decreased and intensity of browsing fell off. Trapping data indicated that the population of snowshoe hares varied from a high of six hares per hectare in the fall of 1971 to a low of 0.12 hare/ha in the spring of 1975. Despite the fact that some hares were trapped in the burned area, there appeared to be no permanent residents there even 3 years after the fire.

Results of trapping and analysis of stomach contents revealed that hares migrate seasonally and substantially change their diet. In summer, they prefer open areas where blueberry, lowbush cranberry, and herbaceous plants are most plentiful. In the winter, hares move back into dense black spruce stands where they feed on spruce, willow, and alder. Even heavy browsing on hardwoods appears to be beneficial; it stimulates lateral branching and, hence, greater productivity.

LITERATURE CITED

Barney, Richard J.
1967. Buildup indexes for interior Alaska, 1956-1965. USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., 49 p. Portland, Oreg.

Barney, Richard J.
1971. Wildfires in Alaska--some historical and projected effects and aspects. *In* Fire in the northern environment--a symposium, p. 51-59, illus., C. W. Slaughter, Richard J. Barney, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Bjorkbom, J. C.
1971. Production and germination of paper birch seed and its dispersal into a forest opening. USDA For. Serv. Res. Pap. NE-209, 14 p. Northeast For. Exp. Stn., Upper Darby, Pa.

Brown, J., W. Richard, and D. Vietor.
1969. The effect of disturbance on permafrost terrain. Spec. Rep. 138, 13 p. Cold Reg. Res. and Eng. Lab., Hanover, N.H.

Brown, R. J. E.
1965. Influence of vegetation on permafrost. *In* Permafrost: Proceedings of an international conference, p. 20-25. Natl. Acad. Sci., Washington, D.C.

Clautice, Stephan Fitzgerald.
1974. Spruce and birch germination on different seedbeds and aspects after fire in interior Alaska. M.S. thesis. Univ. Alaska, Fairbanks. 94 p.

Cody, W. J.
1964. Reindeer range survey, 1957 and 1963. 56 p. Can. Dep. Agric. Plant Res. Inst.

Cushwa, C. T., and K. P. Burnham.
1974. An inexpensive live-trap for snowshoe hares. J. Wildl. Manage. 38(4):939-941.

Dyrness, C. T.
1963. Effects of burning on soil. *In* Symposium on forest watershed management proceedings, p. 291-304. Oreg. State Univ., Corvallis.
Ernest, J.
1974. Snowshoe hare studies. Final report. Fed. Aid Wildl. Restoration Proj. W-17-4, W-17-5, and W-17-6. 46 p. Alaska Dep. Fish and Game, Juneau.
Federal Water Pollution Control Administration.
1968. Water quality criteria: Report of the National Technical Advisory Committee to the Secretary of the Interior. 234 p. Washington, D.C.
Giles, R. H., Jr. (ed.).
1969. Wildlife Management Techniques. 3rd edition. The Wildlife Society. Washington, D.C. 623 p.
Harris, A. S.
1969. Ripening and dispersal of bumper western hemlock-Sitka spruce seed crop in southeast Alaska. USDA For. Serv. Res. Note PNW-105, 11 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
Hegginbottom, J. A.
1971. Some effects of a forest fire on the permafrost active layer at Inuvik, N.W.T. *In* Proceedings of a seminar on the permafrost active layer, May 4-5, 1971, p. 31-36. R. J. E. Brown, ed. Natl. Res. Counc. Can. Tech. Memo. 13.
Heinselman, M. L.
1957. Silvical characteristics of black spruce (*Picea mariana*). USDA For. Serv. Lake States For. Exp. Stn., Stn. Pap. 45, 30 p. St. Paul, Minn.
Johnston, William F.
1972. Seeding black spruce on bushy lowland successful if vegetation density kept low. USDA For. Serv. Res. Note NC-139, 4 p. North Central For. Exp. Stn., St. Paul, Minn.
Kryuchkov, V. V.
1968. [Soils of the far north should be conserved.] Mus. Soil Science, Moscow State Univ. Piroda 12, 7274. (Translated in "The effect of disturbance on permafrost terrain," by J. Brown, W. Richard, D. Vietor, U.S. Army Cold Reg. Res. and Eng. Lab. Spec. Rep. 138, 13 p.)
Lotspeich, Frederick B.
1972. Effects of Wickersham Dome fire on water quality of Washington Creek. Environ. Prot. Agency, Work. Pap. 14, 17 p. Alaska Water Lab., College, Alaska.
Lotspeich, Frederick B., Ernst W. Mueller, and Paul J. Frey.
1970. Effects of large scale forest fire on water quality in interior Alaska. 155 p. U.S. Dep. Inter., Fed. Water Pollut. Control Adm., Alaska Water Lab., Fairbanks.
Lutz, H. J.
1956. Ecological effects of forest fires in the interior of Alaska. USDA For. Serv. Tech. Bull. 1133, 121 p.
Mackay, J. Ross.
1970. Disturbances to the tundra and forest tundra environment of the western arctic. Can. Geotech. J. 7:420-432.

Noste, Nonan V., and James B. Davis.
1975. A critical look at forest damage appraisal. J. For. 73 (11):715-719.
Ohman, Lewis F., and Robert R. Ream.
1971. Wilderness ecology: A method of sampling and summarizing data for plant community classification. USDA For. Serv. Res. Pap. NC-49, 14 p. North Cent. For. Exp. Stn., St. Paul, Minn.
Orloci, L.
1967. An agglomerative method for the classification of plant communities. J. Ecol. 55(1):193-206.
Pruitt, William O., Jr.
1957. Observations on the bioclimate of some taiga mammals. Arctic 10(3):131-138.
Rickard, Warren, and Jerry Brown.
1972. The performance of a frost-tube for the determination of soil freezing and thawing depths. Soil Sci. 113(2):149-154.
Rodin, L. E., and N. I. Bazilevich.
1967. Production and mineral cycling in terrestrial vegetation. 288 p. Oliver and Boyd, Edinburgh and London.
Scotter, George W.
1971. Fire, vegetation, soil, and barren-ground caribou relations in northern Canada. *In* Fire in the northern environment--a symposium, p. 209-230, illus. C. W. Slaughter, Richard J. Barney, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
U.S. Department of Agriculture, Forest Service.
1948. Woody plant seed manual. U.S. Dep. Agric. Misc. Publ. 654, 416 p. Washington, D.C.
Viereck, Leslie A.
1973. Wildfire in the taiga of Alaska. J. Quaternary Res. 3(3):465-495.
Wein, Ross W.
1971. Fire and resources in the subarctic--panel discussion. *In* Fire in the northern environment--a symposium, p. 251. C. W. Slaughter, Richard J. Barney, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
West, Stephen D.
1977. Midwinter aggregation in the northern red-backed vole, *Clethrionomys rutilus*. Can. J. Zool. 55(9):1404-1409.
West, Stephen Douglas.
1974. Post-burn population response of the northern red-backed vole, *Clethrionomys rutilus*, in interior Alaska. M.S. thesis. Univ. Alaska, Fairbanks. 66 p.
West, Stephen Douglas.
1979. Habitat responses of microtene rodents to central Alaskan forest succession. Ph. D. thesis. Univ. Calif., Berkeley. 115 p.
Whitney, Paul.
1976. Population ecology of two sympatric species of subarctic microtine rodents. Ecol. Monogr. 46(1):85-104.
Wilton, W. C.
1963. Black spruce seedfall immediately following fire. For. Chron. 39(4):477-478.

Wolff, Jerry O.
1977. Habitat utilization of snowshoe hares (*Lepus americanus*) in interior Alaska. Ph.D. thesis. Univ. Calif., Berkeley. 150 p.

Wolff, Jerry O.
1978a. Burning and browsing effects on willow growth in interior Alaska. J. Wildl. Manage 42(1):135-140.

Wolff, Jerry O.
1978b. Food habits of snowshoe hares in interior Alaska. J. Wildl. Manage. 42(1):148-153.

Zasada, John C.
1971. Natural regeneration of interior Alaska forests--seed, seedbed, and vegetative reproduction considerations. *In* Fire in the northern environment--a symposium, p. 231-246. C. W. Slaughter, Richard J. Barney, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Zasada, John C., and Leslie A. Viereck.
1970. White spruce cone and seed production in interior Alaska, 1957-68. USDA For. Serv. Res. Note PNW-129, 11 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

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Baseline Climatic and Hydrologic Relationships for the High Ridge Evaluation Area

By
W.B. Fowler,
J.D. Helvey, and
C. Johnson



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Conversion Factors for English Units from Metric Units

To convert:	Into:	Multiply by:
hectares	acres	2.471
kilometers	miles	0.6214
meters	feet	3.281
Celsius	Fahrenheit	(9/5°C)+32
grams per cubic centimeter	pounds per cubic foot	62.43
liters per second	cubic feet per second	0.03531
kilometers per hour	miles per hour	0.6214

Abstract

This report summarizes the climatic and hydrologic measurements taken in the High Ridge evaluation area, a four-watershed complex within the Umatilla barometer watershed of eastern Oregon. The information--measurements of water yield; air, soil, and water temperatures; snow depth and density; and wind--is presented to identify the pretreatment condition and is representative of environmental conditions in similar stands within the Blue Mountain area.

KEYWORDS: Climatography, water supply, temperature (water), temperature (soil), Oregon (Blue Mountains), watershed management.

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Introduction

During the middle 1960's, the Barometer Watershed Program was established by the USDA Forest Service "to meet the need and demand for water information to support Land Use and Program Planning on National Forest system lands."[1]

According to Dortignac and Beattie:[2] The "barometer" watershed program provides the basis for determining the effect of management practices on hydrologic behavior. It is the proving ground for (1) developing and refining watershed prescriptions based on the most recent research findings, (2) making water yield predictions, and (3) comparing predictions with actual performance. The system provides a basis for appraising cost-benefit relationships and suitable demonstration and training areas.

Watersheds were selected to represent a variety of climatic, vegetative, and physiographic conditions. Among these was the Umatilla barometer watershed in the Blue Mountains of eastern Oregon. Included within this 34 000-ha watershed complex was the High Ridge evaluation area with four subwatersheds comprising a total area of approximately 200 ha.

Background and supplemental information for the watershed complex and some details of the evaluation area are available in documents prepared as interim reports by Region 6, USDA Forest Service, Portland, Oregon. These include:

1. Umatilla barometer watershed analysis, 1965.
2. Watershed analysis and prescription - High Ridge evaluation area, Umatilla barometer watershed, 1970.
3. Umatilla barometer watershed, survey-analysis-plan, 1971.
4. Hydrometeorological data bank water years 1965-1975, Umatilla River barometer watershed.
5. Hydrometeorological data bank water year 1976, Umatilla River barometer watershed.

Although the overall objective of this program is to document hydrologic behavior caused by treatments, the baseline data collected during the pretreatment phase are representative of conditions in a larger block of untreated stands within the Blue Mountain area. Any information describing climate or hydrology of these stands is extremely limited. The data presented, therefore, provide the basis for evaluating treatment effects and are an aid to understanding present conditions and the potentials for these stands. Evaluating treatment effects will require a number of years for collection of posttreatment data. The utility of the information presented in this report to present land managers outweighs any advantage of waiting to accomplish the primary objective of the study. Also, data presented here will assist others who are studying the plant and animal interrelationships in these watersheds. These are the only baseline data available on temperatures (air, water, soil), wind, and seasonal distribution of snow; they are not duplicated in interim reports.

The Study Area

The study area (fig. 1) is located in the Blue Mountains of northeastern Oregon, about 22 km northwest of Elgin and 8 km southwest of the Spout

[1] Hydrometeorological data bank water year 1977. May 1978. Umatilla River barometer watershed and Mill Creek municipal watershed. Umatilla Natl. For., USDA For. Serv. Pac. Northwest Reg.

[2] E. J. Dortignac and B. Beattie. 1965. Using representative watersheds to manage forest and range lands for improved water yields. Paper presented at International Association of Scientific Hydrology, Budapest, Hungary, October 5, 1965.



Figure 1.--The High Ridge evaluation area.

Springs Recreation Area. It consists of four individual watersheds containing 24.4, 29.6, 53.3, and 118.1 ha of drainage area. Elevation varies from 1 439 to 1 617 m; slopes vary from 2 to 25 percent; and aspect is generally northeast. The area is densely stocked with a mixture of grand fir (*Abies grandis*), Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), western larch (*Larix occidentalis*), Douglas-fir (*Pseudotsuga menziesii*), and lodgepole pine (*Pinus contorta*).

Methods

Precipitation

Beginning October 1, 1967, precipitation was recorded by a gage located in a natural opening near the center of the four watersheds at 1 493-m elevation. Five other recording gages and 12 storage gages are distributed over the Umatilla barometer watershed between the 731- and 1 706-m elevation.

Density and depth of snow have been measured at each recording site since 1970. In 1972, two plots were located in watershed 1 and one plot each in watersheds 3 (the control) and 4 for intensive snow measurements. The plots are approximately circular in shape and 0.3 ha in area. A stem map, such as that shown in figure 2, was made for each plot.

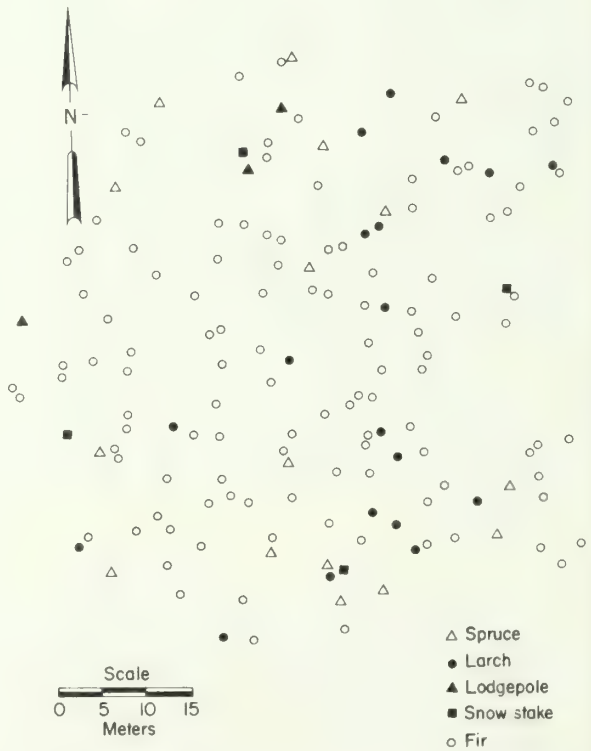


Figure 2.--Stem map for snow depth plot in control watershed 3.

Depth and density of snow on the plots were measured periodically with a snow tube. In addition, at the approximate time of maximum annual snow accumulations in 1972-76, each tree was marked with paint at the snow surface. After snowmelt, the height of each mark was measured and recorded by tree number.

Precipitation data were analyzed for:

1. Total annual amounts and the year-to-year variation.
2. Monthly average and the amounts recorded as rain and snow.
3. Maximum intensities per hour and per day during winter and summer months.
4. Changes in depth and density of snow over time.
5. Variance for selected dates to test the null hypothesis that snow accumulation did not differ significantly (P=0.05) between plots.
6. Maximum annual accumulations of snow to determine maximum depths of snow at frequencies of 5, 10, 25, and 50 years.

Streamflow

Stream flow is measured with modified V-notch weirs (fig. 3). A concrete cutoff wall forces the water through the control section. The control section consists of a V-notch cut in a steel plate that is attached to a fiberglass, trapezoidal flume. Notch sizes are 90^{o} for watershed 2, 60^{o} for watersheds 1 and 3, and 120^{o} for watershed 4. Water level is measured with analog-to-digital recorders.

Summarized data were analyzed for:

1. Annual amounts and year-to-year variations.
2. Correlation of annual runoff with annual precipitation.



Figure 3.--Typical streamflow measuring section.

3. Runoff characteristics expressed as flow-duration curves.
4. Correlation of annual runoff between watershed 3 (the control) and each of the other watersheds.
5. Prediction of peak discharge for recurrence periods of 5, 10, 25, and 50 years.

Air, Soil, and Water Temperatures

Location of the High Ridge area precluded installation of equipment that would require continuing service. A new type of integrating temperature system with a digital printer was designed to satisfy data needs. Instruments print a degree-hour summary after each 3 hours, permitting calculation of average temperature for the period or accumulation of degree-hour summaries. A value of $-10^{o}C$ was selected as the base for the degree-hour summary; $-10^{o}C$ is thus the lower limit for any temperature measurement. In the several years of record, during only about 2 weeks a year was the temperature colder than $-10^{o}C$.

Units are buried for temperature stability and to prevent vandalism. Tapes are collected twice a year. A simple calculator program summarizes the measurements. Soil temperatures were not evaluated before 1976.

Speed and Direction of Wind

A new "Adaptive Speed and Direction Analyzer" (Fowler 1977) was designed for the High Ridge study to provide an onsite summary of windspeed within several speed classes and a summary of wind direction corresponding to these classes. Memory storage is adequate for collecting data up to 2 months. More frequent readouts, usually at monthly intervals, were made to improve the overall resolution.

Units accumulate data based on a 134.08-m travel distance with direction resolved to quadrants. No wind direction data are accumulated if air movement is absent.

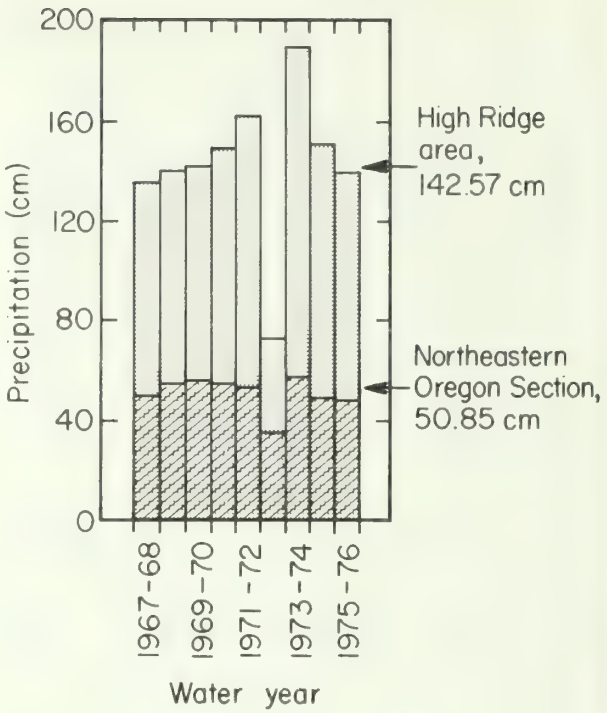


Figure 4.--Average annual precipitation for High Ridge area and Northeastern Oregon Section.

Results and Discussion

Precipitation

Average annual precipitation for the High Ridge area for 1967-76 is 142.47 cm. Annual amounts vary (fig. 4) between a high of 190.25 cm and a low of 73.15. Average regional precipitation for stations in the surrounding area--designated by National Oceanic and Atmospheric Administration as the "Northeastern Oregon Section"--is also shown in figure 4. Spatial averaging and inclusion of primarily lowland stations reduce the variability and lower average annual amounts to about a third (51 cm) of the High Ridge average.

Precipitation is primarily a cool season phenomenon throughout the Pacific Northwest States. Storm tracks for extra tropical cyclones concentrate along the northern tier of States. Strong airmass contrasts, mild, moist Pacific air, and frigid continental polar air produce vigorous storms. Local amounts of precipitation are strongly influenced by topography. The seasonal distribution of precipitation by months is illustrated in figure 5. For the High Ridge area, 87 percent of the yearly total precipitation falls between October 1 and May 31; 13 percent in the summer months, June through September. For the Northeastern Oregon Section, corresponding figures are 79 percent and 21 percent. Topographic influences on precipitation in the cool season account for the major differences between lowland and mountain sites. Compared with lowland sites, the High Ridge location receives three times as much precipitation per month in

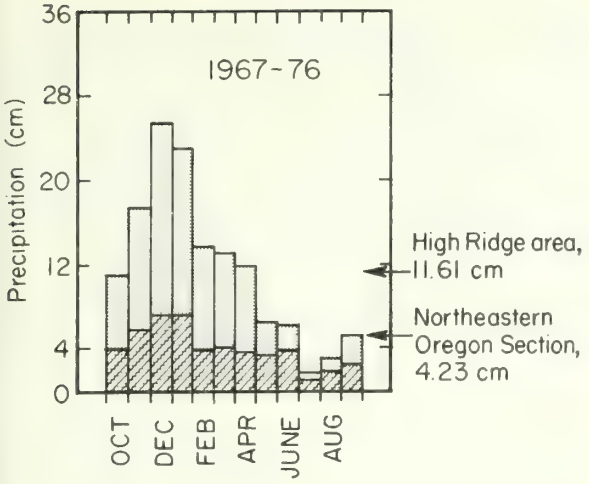


Figure 5.--Average monthly precipitation for High Ridge area and Northeastern Oregon Section.

the cool season but less than twice as much in the summer season.

Precipitation per day can amount to nearly 10 cm at these high elevation sites during winter storms (mixed rain and snow) or in intense, highly localized thunderstorms. Thunderstorm activity, based on a 7-year study (Morris 1934), is more prominent immediately to the east of the High Ridge location; however, the expectation is for between five and six lightning storms per 40 000 ha per year at this location. The individual cells of thunderstorms follow a southwest to northeast path over an 80- to 100-km traverse. Although intense thunderstorm paths may be up to 60 km wide (Morris 1934), precipitation values normally decline rapidly with distance from thunderstorm centers. Because stations in the High Ridge area are 7 to 10 km apart, situations occur where heavy rainfall (up to 10 cm) may be recorded at only one of the gages.

As air temperature decreases in the fall months, precipitation changes from rain to snow. The first few snowstorms may melt as temperatures fluctuate above and below freezing. In most years, a snowpack usually begins to form by late November. It increases in depth and water content until late March or early April; then the snow gradually melts. Complete snowmelt varies from year to year, depending on maximum accumulation of snow and energy input in the early spring. The last snow usually is melted by early June.

Figure 6 illustrates the depth and density of the snowpack in 1973. The depth inside the watershed averaged 60 cm on January 12 when it was first measured. At that time, snow density was 0.22 g/cm^3, and the total water content was 13 cm. Snow depth, density, and water content increased until April 3 when depth was 88 cm; density, 0.33 g/cm^3; and water content, 29 cm. The date of maximum accumulation could not be determined from these measurements because of

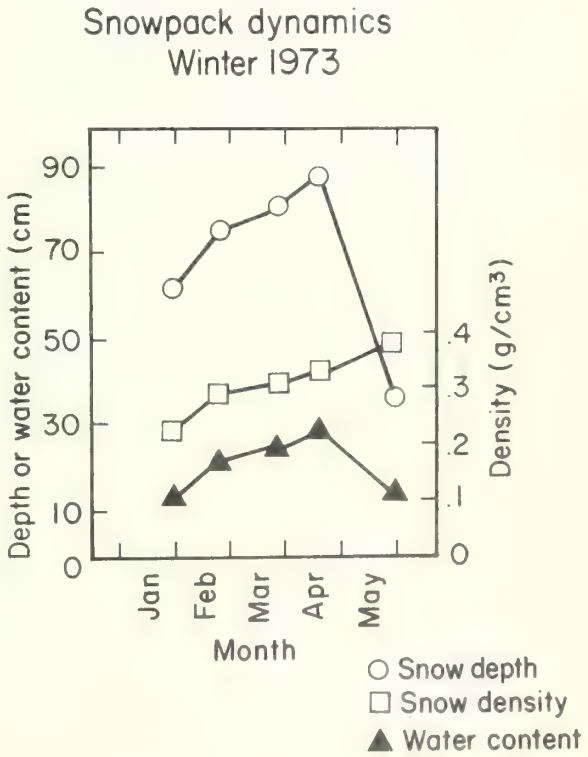


Figure 6.--Depth-density relationship for snowpack in 1973.

the infrequent sampling schedules, but the April 3 value is probably close to the maximum. On May 14, when the last measurement was made, snow depth had declined to 36 cm, but density had increased to 0.38 g/cm^3. Water content was only 12 cm.

Table 1 lists the average depth of snow on the approximate date of annual maximum accumulation in 1972-77. A simple t test indicated no significant differences (P=0.05) in snow depth between plots. The within-plot variation was quite high because of uneven snow deposition under the dense tree canopy. For example, on April 4, 1972, snow depth on one plot varied from 127 to 257 cm.

Streamflow

Because flow rates are lowest in late summer, the water year is defined as extending from October 1 to September 30. Runoff rates are low in winter months as the snowpack increases in depth and water content. Along with increases in air temperature in early spring, flow rates increase and the maximum annual peak occurs in May or June. Flow rates gradually diminished throughout the summer because evapotranspiration losses exceed current amounts of precipitation. About 80 percent of the total annual flow occurs during May and June in response to snowmelt. All the watersheds show some response to the general increase in rainfall during the early fall months. Average annual runoff for the 1967-76 period was 43.9, 51.6, 51.8, and 47.2 cm from watersheds 1, 2, 3, and 4, respectively. The annual range is from 16.4 to 88.0 cm for watershed 1; 22.6 to 82.8 cm for watershed 2; 14.6 to 87.7 cm for watershed 3; and 21.1 to 72.0 for watershed 4.

If (1) precipitation is measured accurately, (2) there is little or no deep seepage, and (3) runoff is measured accurately, the difference between annual precipitation and annual runoff is the amount of water lost to evaporation and transpiration. Average annual precipitation minus average annual runoff for the High Ridge watersheds was 96.2, 88.5, 88.3, and 92.9 cm for watersheds 1, 2, 3, and 4, respectively. These values may be greater than actual evapo-

Table 1--Average depth of snow within four watersheds when depth was near the annual maximum, High Ridge area

Date or statistical parameter	Watershed 4	Watershed 3 (control)	Watershed 1		Mean
			Upper	Lower	
		Centimeters			
4-4-72	194	175	163	164	174.0
4-2-73	98	86	80	82	86.5
3-19-74	240	265	241	248	248.5
3-15-75	136	126	115	119	124.0
3-2-76	200	214	186	196	199.0
3-22-77	96	89	88	83	89.0
Mean	160.7	159.3	145.5	148.7	153.6
Variance	59.6	71.9	62.8	66.2	65.1
Standard deviation	12.4	13.5	12.6	13.0	12.9
Coefficient of variation	97.0	106.4	99.4	102.1	101.2
Standard error	5.1	5.5	5.1	5.3	5.27

transpiration because there appears to be a good possibility for some deep seepage into the fractured basalt bedrock.

Flow duration curves provide a useful way to study runoff patterns. These curves (fig. 7) show the percent of time that flow rate is above

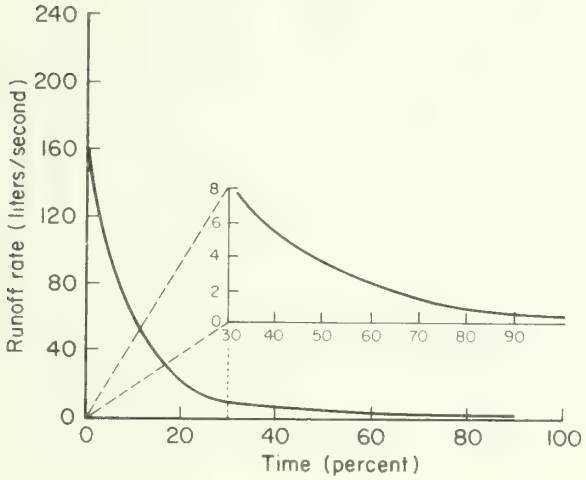


Figure 7.--Flow duration curves for watershed 4.

or below a given value. For example, figure 7 shows that runoff rate from watershed 4 was greater than 3.82 liters per second one-half of the time, and it was greater than 65.1 liters per second 10 percent of the time between October 1, 1967, and September 30, 1975. The maximum and minimum flow rates were 240.6 liters and 0.28 liter per second. Flow duration curves for the other watersheds have a similar shape, but the values are smaller because of smaller drainage areas. These curves are useful for detecting changes in the hydrograph after timber harvest. For example, an analysis after timber harvest may show that low flow rates increased significantly. Tests can also be made to determine whether peak flow rates increased after timber harvest.

When a new forest road is built, culverts or other structures must be installed at stream crossings to carry expected runoff under the road. What size culvert should be installed? This is an extremely important decision because an undersize culvert may be overtopped and a section of road destroyed. On the other hand, installing a culvert larger than needed wasts finances.

Experienced land managers can make an intelligent estimate of the size of culvert needed by observing the width and high water marks of the stream channel. When runoff records are available, a better estimate can be obtained by applying the laws of probability to measured runoff peaks. Although there are several methods available, the Log Pearson Type 3 method (United States Water Resources Council 1976) is recognized as the most accurate.

This method was applied to measured annual runoff peaks from the four streams at High Ridge. The ratio of maximum to minimum runoff peak during the 10 years of record varied from 11 on the smallest drainage to 4 on the largest. Peak discharge was computed for each drainage at recurrence intervals of 2, 5, 10, 25, and 50 years (table 2).

Figure 8 shows the expected peak discharge for each watershed as a function of the selected recurrence periods. The 10-year flood peak on watershed 4 is about 240.7 liters per second, and the 25-year flood peak is 283.2 liters per second. It is well recognized that peak discharge is a function of drainage area. Figure 9 illustrates a close relationship between drainage area and expected peak discharge at 5- and 25-year recurrence periods. This figure can be used to predict peak discharge in headwater streams of the Blue Mountains which have similar

Table 2--Computed peak discharge at selected recurrence intervals for 4 watersheds, High Ridge area

Recurrence interval	Watershed			
	1	2	3	4
Years	- - - Liters per second - - -			
2	42.8	49.7	102.6	176.3
5	76.4	65.1	135.8	237.7
10	90.6	70.8	158.5	263.2
25	107.5	76.4	186.8	285.8
50	116.0	79.2	206.6	300.0

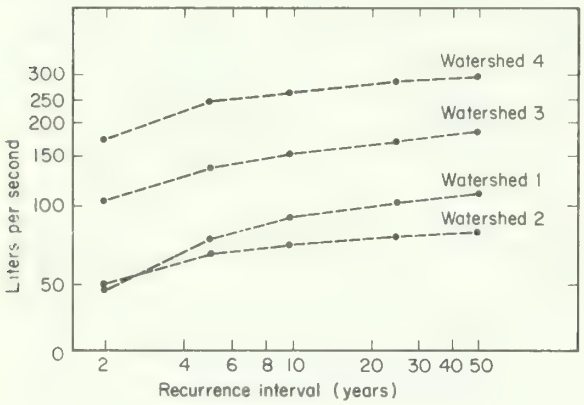


Figure 8.--Peak discharge for High Ridge watersheds as a function of recurrence period.

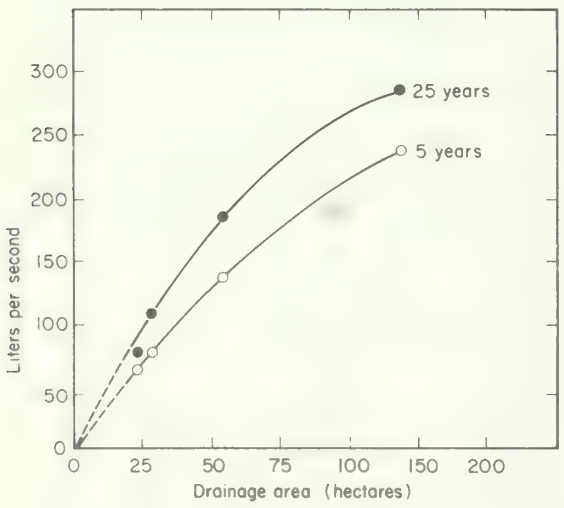


Figure 9.--Relationship between drainage area and peak discharge for 5- and 25-year periods.

exposure, vegetation, and annual precipitation to that of the High Ridge area.

The size of culvert needed for a given peak discharge rate depends on channel slope. Detailed methods for determining the relationship between channel slope, culvert size, and flow capacity were presented by Carter (1957) and Douglass (1974).

One of the original objectives of the High Ridge evaluation area was to determine the effects of timber harvest on water yield. This analysis requires linear regressions of annual runoff between watershed 3 (the control) and each of the other watersheds. The ability to detect changes in runoff after timber harvest depends on the degree of correlation between runoff from the control and each of the other watersheds. The data and regressions are plotted in figures 10,

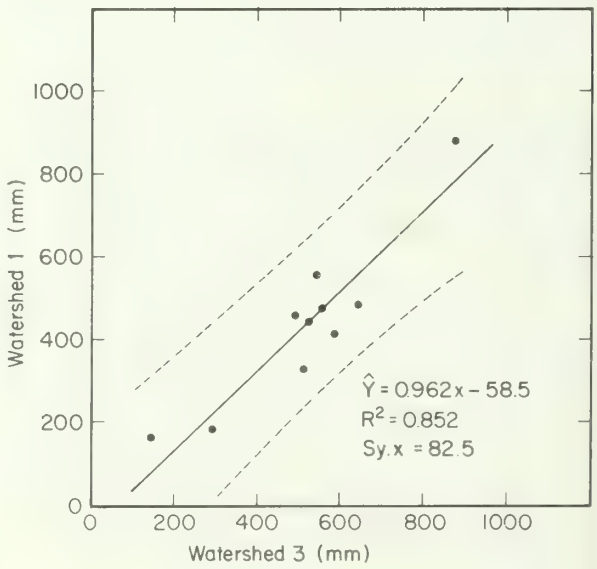


Figure 10.--Relationship between annual runoff, watershed 3 (control) and watershed 1. Solid line is plot of best fit regression equation. Dotted lines are 95-percent confidence limits for individual measurements.

11, and 12. Confidence bands (95-percent probability) apply to an individual measurement of runoff.

The correlation values for watersheds 2 and 4 indicate that most of the variation in runoff from these drainages is associated with runoff from watershed 3. The correlation of runoff between watershed 1 and 3 is lower. Increases in runoff after timber harvest from watershed 1 must exceed 19 cm during an average year to be statistically significant at the 95-percent probability level and 15 cm at the 90-percent level.

Soil Temperature

Canopy closure and limited air movement within the stand reduce energy input to the soil surface. Snow cover maintains isothermal conditions (near 0°C) from first snowfall to early June or mid-June. Maximum temperatures for watershed 4 in 1976, for example, at 2 cm did not exceed 20.6°C; at 10 cm, 15.5°C. Diurnal ranges of 8°-10°C were observed in the summer months.

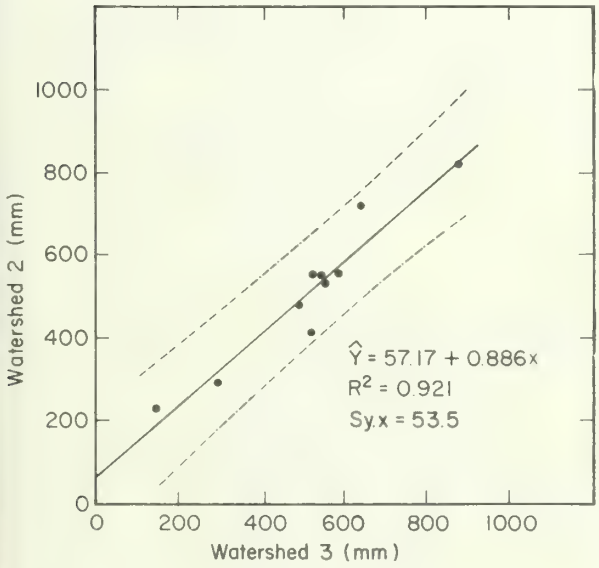


Figure 11.--Relationship between annual runoff, watershed 3 (control) and watershed 2. Solid line is plot of best fit regression equation. Dotted lines are 95-percent confidence limits for individual measurements.

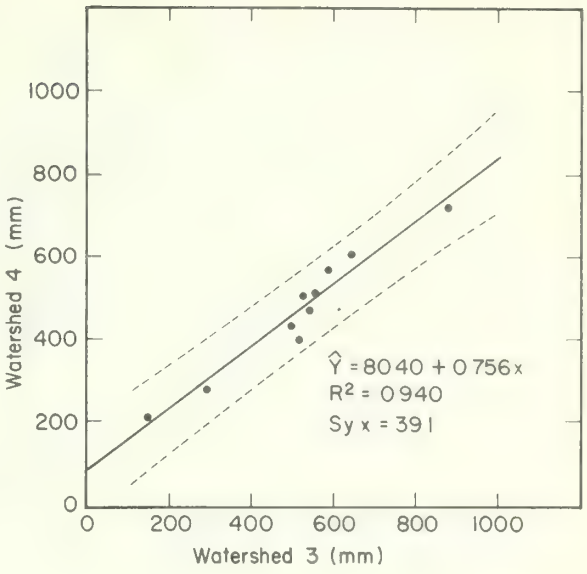


Figure 12.--Relationship between annual runoff, watershed 3 (control) and watershed 4. Solid line is plot of best fit regression equation. Dotted lines are 95-percent confidence limits for individual measurements.

Water Temperature

Stream temperatures follow an expected seasonal trend strongly influenced by duration of snow cover and flow regime. Figure 13 illustrates the temperature progression of maximum and minimum 3-hour averages for watershed 4 for the years 1973 through 1976. Temperatures of the snow-covered streams range between 1°C and 2°C; diurnal range is about 0.5°C. This conditon persists through the peak runoff period; stream temperatures

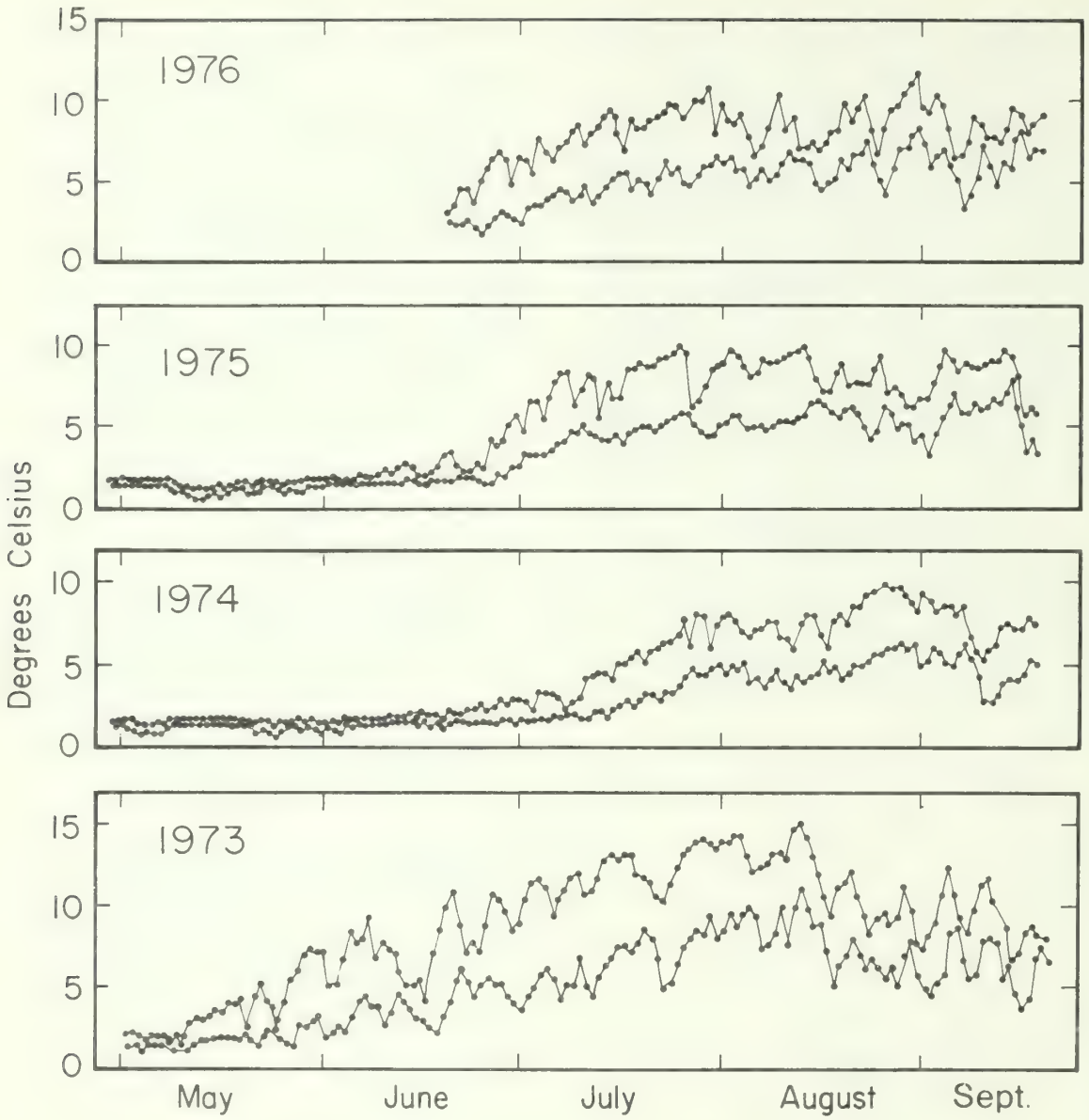


Figure 13.--Maximum and minimum 3-hour average stream temperatures for watershed 4 during spring and summer, 1973 through 1976.

start to rise during the recession part of the streamflow curve.

During average precipitation years 1974, 1975, and 1976, temperature maximums for all streams rarely exceeded 10°C; during the summer months minimums rose into the 6°C range. In the dry year of 1973, maximum water temperatures were closer to 12°C during the months of July and August and minimum temperatures near 10°C, the expected maximum during wetter years.

A frequency distribution of water temperature from watershed 4 between September 21, 1972, and September 20, 1976, is illustrated in figure 14. The annual distribution indicates that stream temperature was between 0°C and 2°C for 59.5 percent of the

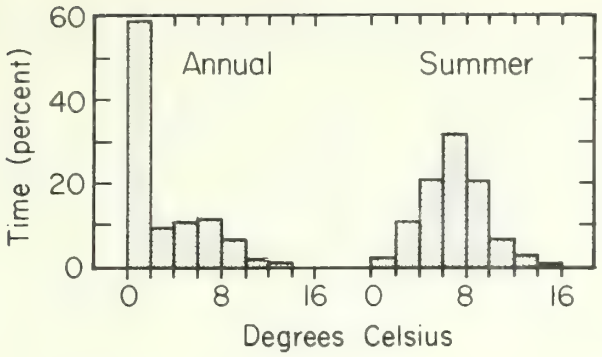


Figure 14.--Frequency distribution of 3-hour average stream temperature for watershed 4.

time. This distribution is heavily weighted toward the lower temperature because the streams are covered with snow about 6 months of the year. When summer temperatures alone are plotted, a normal distribution with a mean range of 6°C to 8°C results.

Watersheds 1, 2, and 3 (the control) show similar seasonal trends. Day-to-day variability in water temperature appears to be inversely related to amount of streamflow during the summer months, whereas diurnal range is larger as flow increases. Watershed 1 has the highest day-to-day temperature fluctuation, the lowest diurnal range, and often the lowest annual runoff of the four watersheds.

The degree-hour summaries of water temperatures for the individual 3-hour periods of the day (fig. 15) illustrate the period of maximum daily heating and cooling. During this period in the summer of 1974, watershed 3, the control watershed, exhibits overall values similar to those of watershed 4, the adjacent watershed. Periods of minimum degree-hour accumulation are between 0600 and 0900 hours, as expected, for all watersheds. Maximum degree-hour accumulation in watershed 3 occurs between 1200 and 1500 hours; other watersheds show the maximum accumulation between 1500 and 1800 hours.

Figure 16 illustrates the relationship between daily maximum temperatures for stream and air for watershed 4 during 1974. Stream temperatures, as noted, are nearly isothermal for a large portion of the year, and

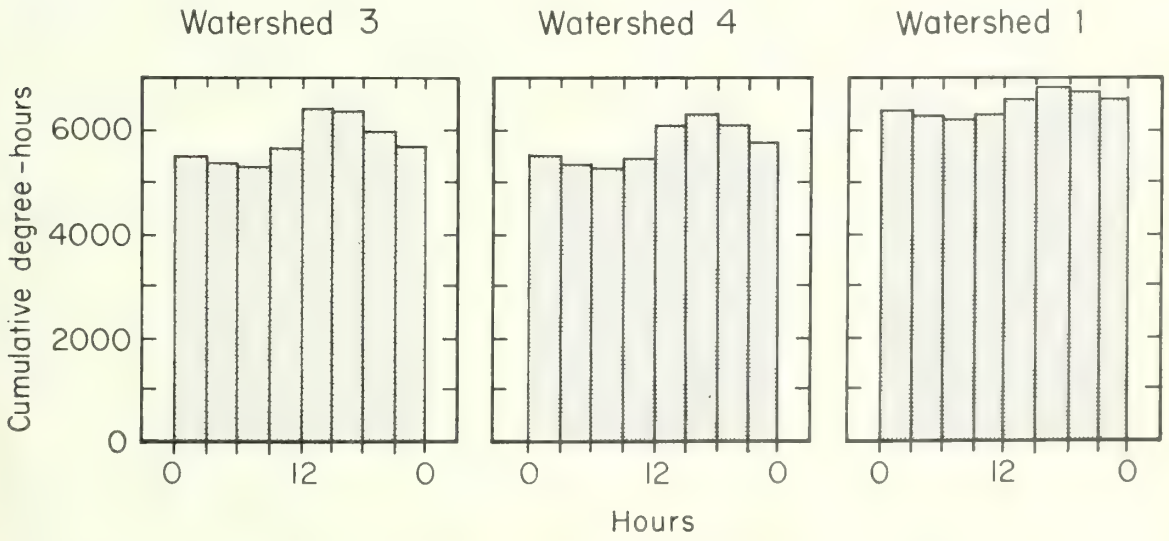


Figure 15.--Degree-hour summaries for 3-hour periods for watershed 1, 3 (control), and 4.

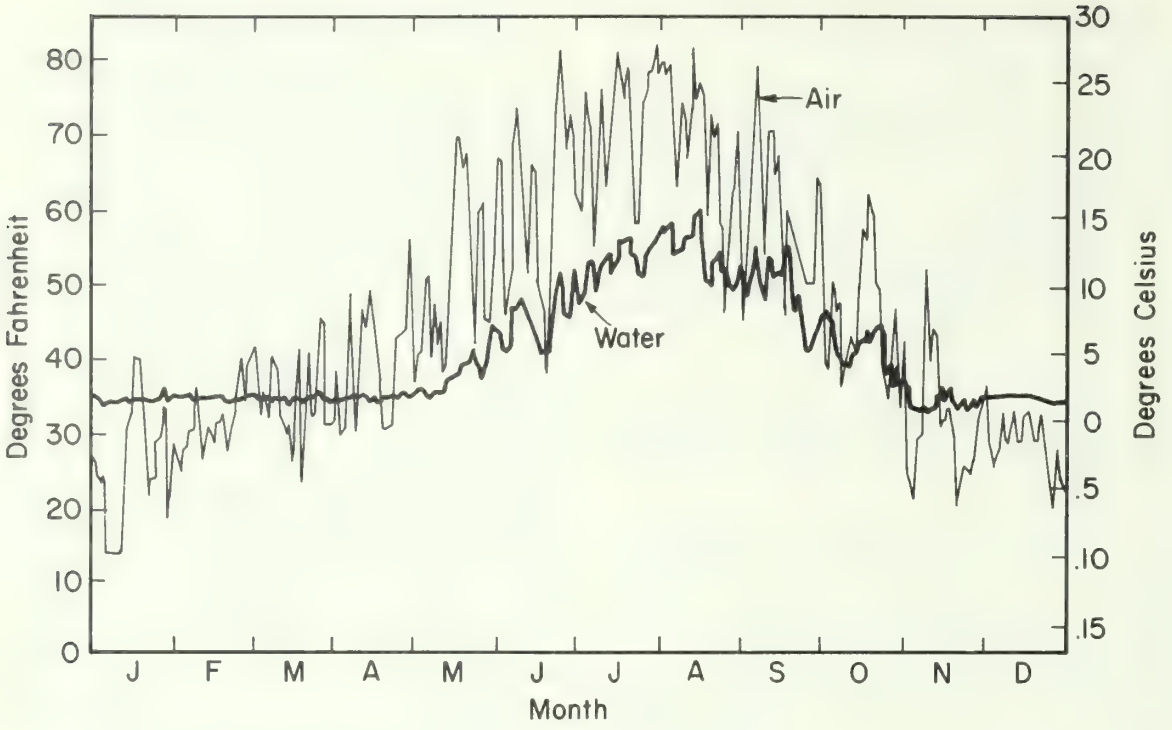


Figure 16.--Relationship between daily maximum air and water temperatures for watershed 4 (1974).

day-to-day fluctuations are small compared with the variation in air temperatures. The coefficient of determination, R^2, between air and water temperatures in watershed 4 was 0.63.

During winter months, water temperatures are near 0°C under the several feet of snow cover. Correlation of water temperatures between watersheds would obviously be near unity. Table 3 lists the computed relationships for two periods--March 21 to October 12, 1973, and June 8 to September 14, 1973. The strongest relationship is between watersheds 3 and 4; between watersheds 3 and 2, the weakest. Figures 17, 18, and 19 illustrate these relationships for both maximum and minimum daily temperatures during the summer of 1973.

Table 3--Relationships between water temperatures in watershed 3 (control) and treatment watersheds during calibration period

Watersheds and period	Regression equation	R^2 [1/]	n [2/]
March 21 to October 12, 1973:			
3-4 (min.)	$\hat{y}$=1.038x-0.4241	0.98	206
(max.)	$\hat{y}$=1.098x-0.2502	.98	206
3-2 (min.)	$\hat{y}$=0.9517x+0.0581	.90	206
(max.)	$\hat{y}$=0.9447x+0.3759	.90	206
June 8 to September 14, 1973:			
3-4 (min.)	$\hat{y}$=1.0168x-0.2766	0.97	99
(max.)	$\hat{y}$=1.0826x-0.0924	.97	99
3-2 (min.)	$\hat{y}$=0.8738x+0.6887	.80	99
(max.)	$\hat{y}$=0.8514x+1.2098	.60	99
3-1 (min.)	$\hat{y}$=1.1877x+0.6925	.83	99
(max.)	$\hat{y}$=0.9893x+1.0001	.83	99

[1/] Coefficient of determination.
[2/] Number of samples.

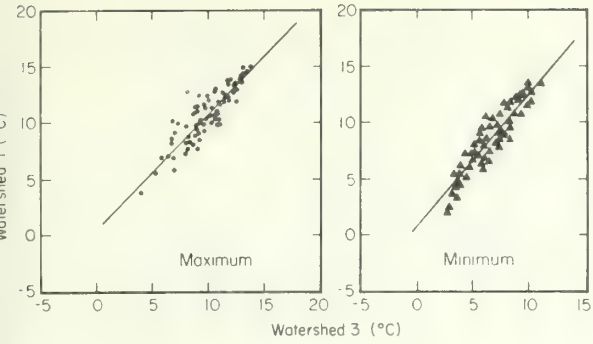


Figure 17.--Comparison of maximum and minimum water temperatures of watershed 3 with those of watershed 1.

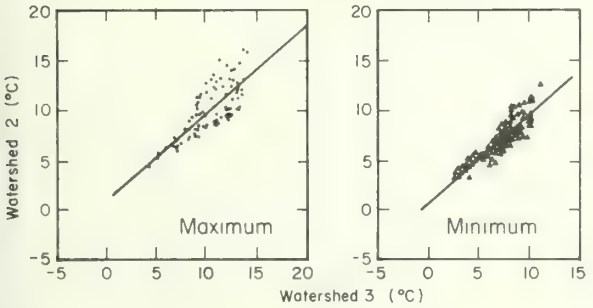


Figure 18.--Comparison of maximum and minimum water temperatures of watershed 3 (control) with those of watershed 2.

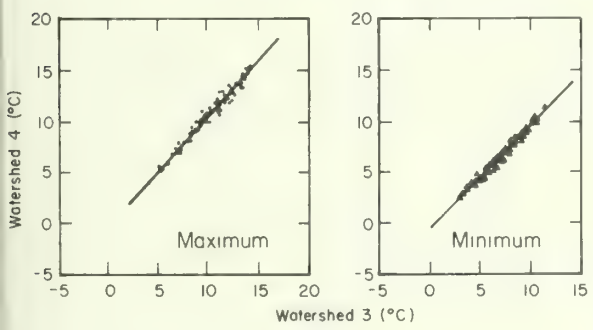


Figure 19.--Comparison of maximum and minimum water temperatures of watershed 3 (control) with those of watershed 4.

Wind

The dense canopy of the mature stand rapidly attentuates the penetration of wind into the depth of canopy and trunk space. Measurements were taken at 6 m in watersheds 1, 3, and 4 and at 20 m in watersheds 1 and 4.

Wind at 6 m in all watersheds rarely exceeded 9.6 km per hour. For instance, in watershed 1 from January 19, 1972, to July 9, 1976, when the recorder was removed prior to logging, only 3.08 km of wind travel were at speeds greater than 9.6 km per hour. Total wind travel for this period was 4 674 km; average speed was only 0.16 km per hour.

At 20 m in watershed 4 (at the main canopy level) between August 14, 1975, and July 9, 1976, total wind travel was 23 665 km, over four times that of watershed 1. This total was distributed among windspeed classes as follows:

Speed (km/h)	Total travel (km)
0-9.59	18 076
9.60-16.09	4 768
16.10-24.09	763
24.10-31.19	53
31.20-48.29	5
48.30+	0

Average windspeed for the period was 3.3 km/h.

Wind direction varied with location. Although the directional constancy of winds below 9.6 km/h, the speed class most commonly observed at the 6-m and 20-m levels beneath the canopy, is normally quite low, some preference is shown in the direction classes as follows:

Watershed	Height (Meters)	Period	Total travel by quadrants			
			N	S	E	W
			Percent			
1	6	8-14-75 to 7-9-76	27	54	18	1
3	6	10-14-72 to 3-7-73	7	41	51	2
4	6	10-15-75 to 7-9-76	23	25	37	15
1	20	8-14-75 to 7-9-76	24	33	30	12
4	20	8-14-75 to 7-9-76	17	59	9	16

Immediate and substantial changes in both speed and direction of wind are expected to occur with removal of canopy in these watersheds.

At 20 m in watershed 1 (beneath the live canopy which extended to 30 m or more), only 12.6 km of wind between August 14, 1975, and July 9, 1976, exceeded 9.6 km per hour. Total wind travel was 5 160 km, and average speed was 0.67 km per hour.

Air Temperature

Figure 20 illustrates the maximum and minimum air temperatures for watershed 3, the control, for a dry year (1973) and an "average" year (1975). Temperatures in the dry year are generally warmer, especially in the early spring and summer months.

Figure 21 shows the accumulation of air temperature degree-hours for the watersheds for several periods during summer and fall of 1974. Periods are of about 6 weeks. Data for watershed 2 for the initial perio were not available. Periods of maximum and minimum temperatures fall generally within the same 3-hour periods within all watersheds. Infrequently, the maximum 3-hour degree-hour accumulation will fall within the 1500-1800 time periods, but generally maximum accumulation is during hours 1200-1500 and minimum between 0300 and 0600 hours.

The greater diurnal temperature range in watershed 4 can be seen by the lower accumulation of degree-hour during the three 3-hour periods from 0000 to 0900 in the graph for watershed 4 (lower right in fig. 21). The index line is at 4 000 degree-hours.

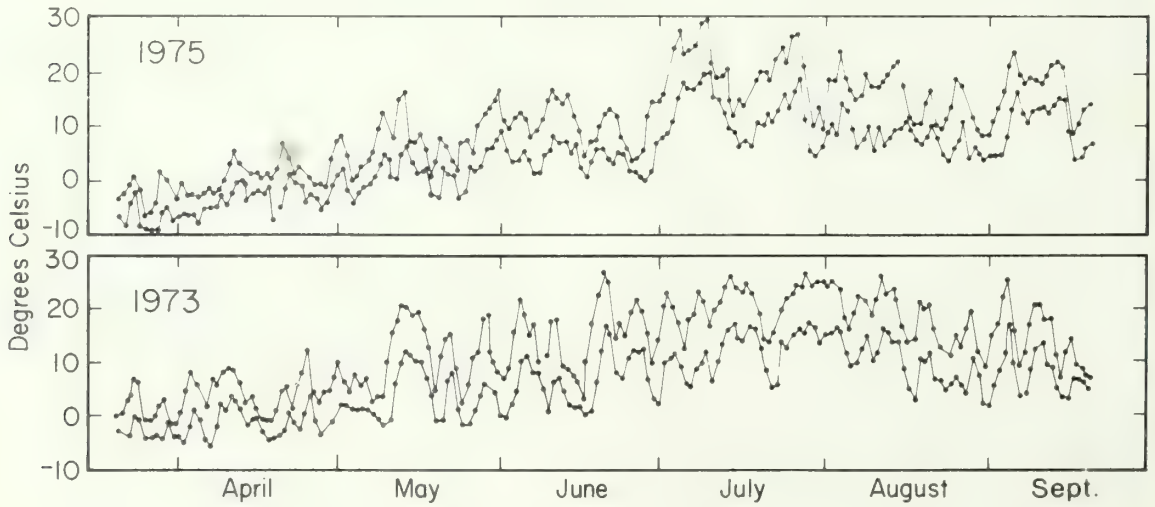


Figure 20.--Maximum and minimum air temperatures for watershed 3 (control) during spring and summer, 1973 and 1975.

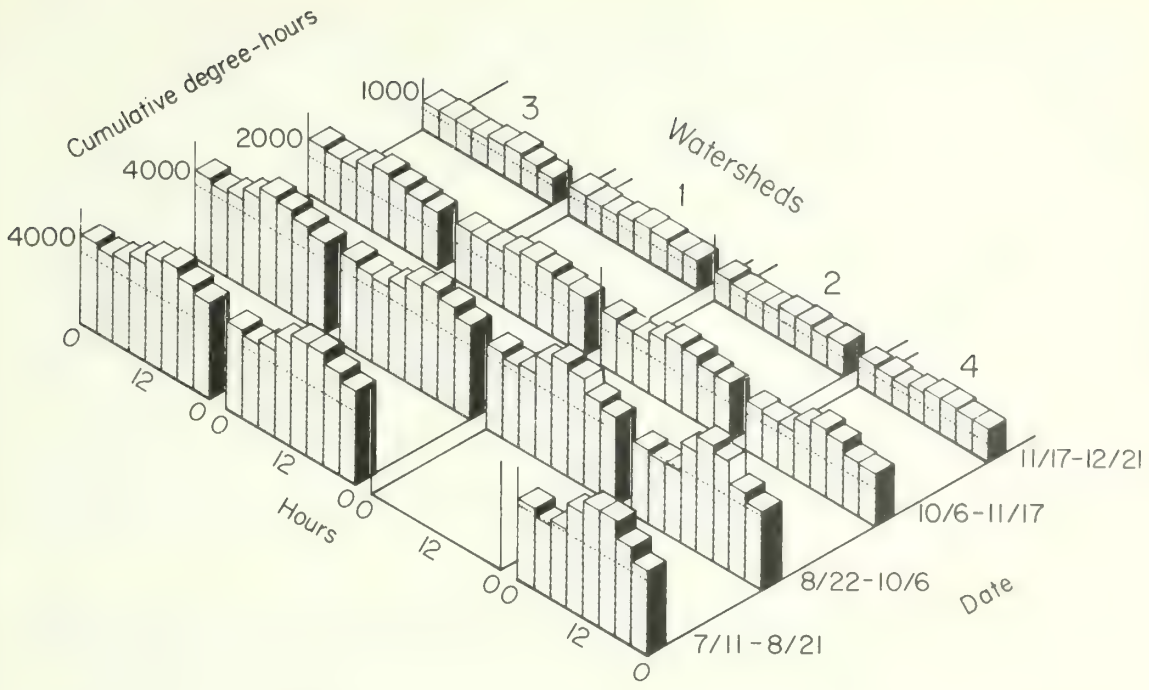


Figure 21.--Accumulation of air temperature degree-hours for selected periods during 1974.

Daytime maximum temperatures are similar within all watersheds.

Correlation coefficients and regression equations for the comparisons between air temperature in watershed 3 (control) and other watersheds are given in table 4. Figures 22, 23, and 24 are graphs of the maximum and minimum temperatures for the calibration period. Maximum temperatures are generally better correlated for all combinations than are minimum temperatures.

From the larger diurnal range exhibited in watershed 4, a location with a less dense overstory than other sites, the expected change in the temperature structure after timber harvest can be seen. We may anticipate further increases in the diurnal range in watershed 4 and at other sites with increased exposure.

The initial timber harvest was made in 1976. A cursory look at the post-harvest data indicates that some hydroclimatic variables were markedly changed. Present plans are to continue measurements for about 3 years, then to analyze and publish the results.

Table 4--Relationships between air temperatures in watershed 3 (control) and treatment watersheds during calibration period

Watersheds and periods	Regression equation	R^2 [1/]	n [2/]
July 14 to December 20, 1974:			
3-4 (min.)	$\hat{y}$=-0.4665+0.7138x	0.94	132
(max.)	$\hat{y}$=0.4955+0.9978x	.99	133
3-1 (min.)	$\hat{y}$=0.3262+0.9493x	.99	142
(max.)	$\hat{y}$=0.2256+0.9783x	.99	142
August 22 to December 20, 1974:			
3-2 (min.)	$\hat{y}$=-0.0089+0.9081x	.97	122
(max.)	$\hat{y}$=0.0402+1.0020x	.99	122

[1/] Coefficient of determination.

[2/] Number of samples (varied because of missing data).

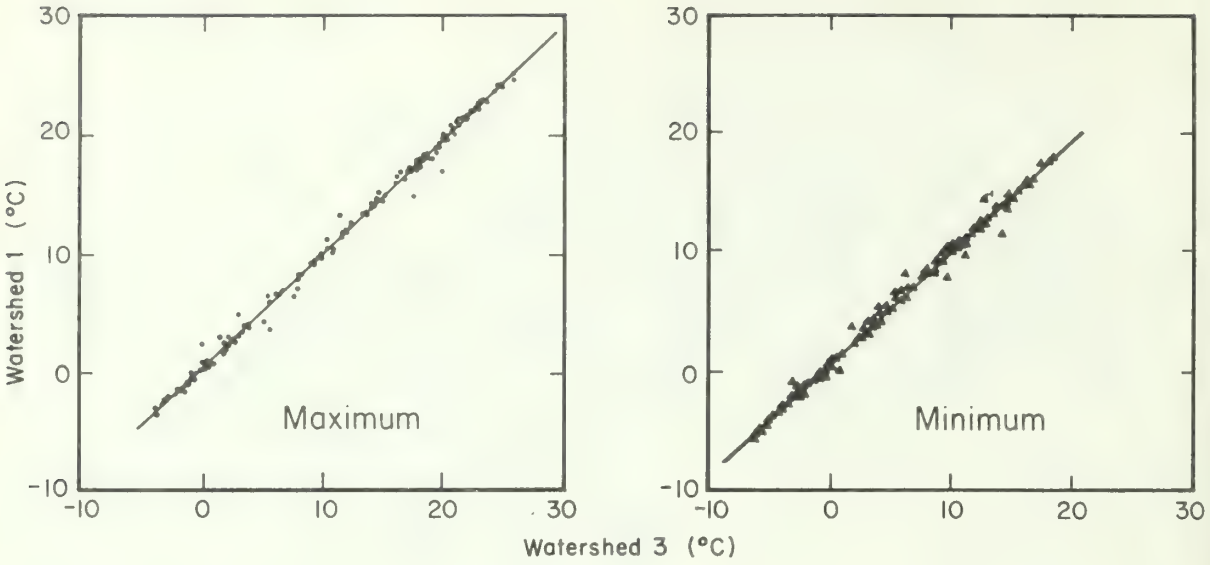


Figure 22.--Relationship between maximum and minimum air temperatures in watershed 3 (control) and watershed 1.

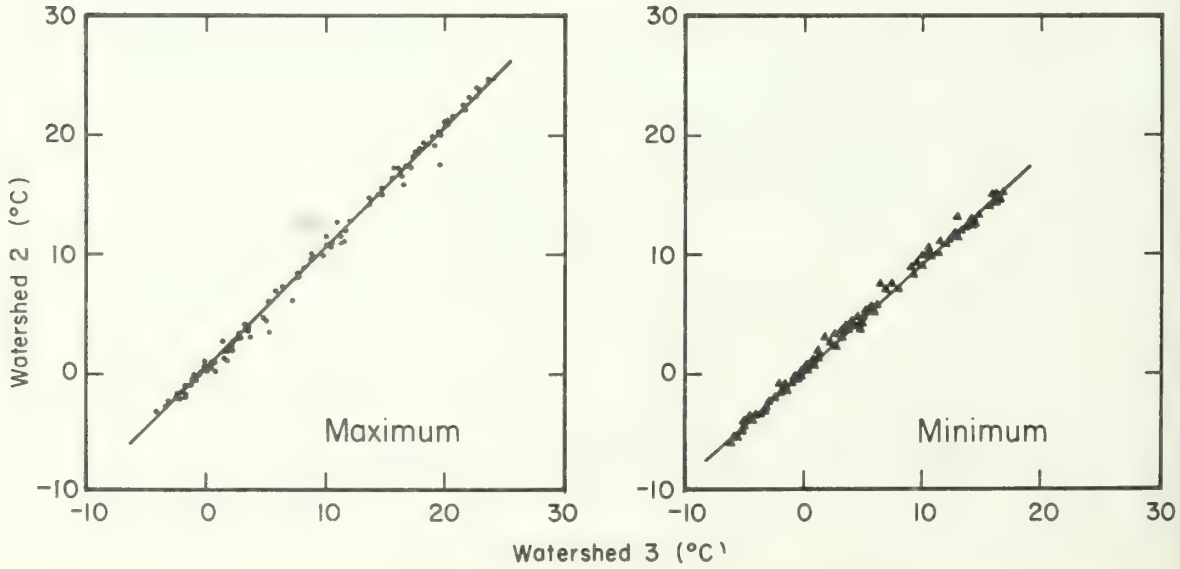


Figure 23.--Relationship between maximum and minimum air temperatures in watershed 3 (control) and watershed 2.

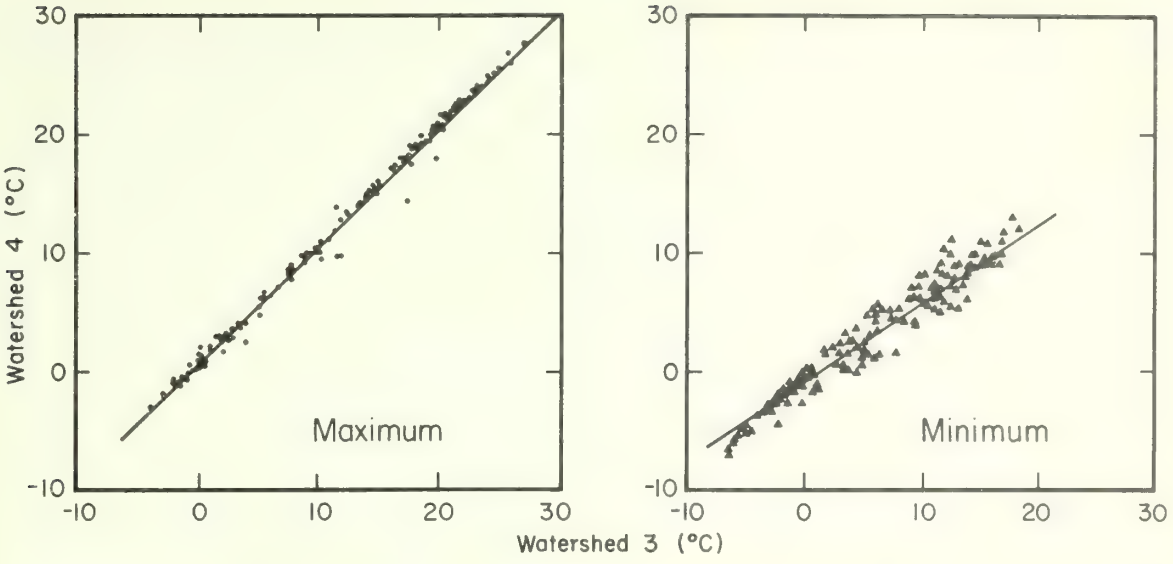


Figure 24.--Relationship between maximum and minimum air temperatures in watershed 3 (control) and watershed 4.

Literature Cited

Carter, R. W.
1957. Computation of peak discharge at culverts. U.S. Dep. Inter. Geol. Surv. Circ. 396, 25 p.

Douglass, James E.
1974. Flood frequencies and bridge and culvert sizes for forested mountains of North Carolina. USDA For. Serv. Gen. Tech. Rep. SE-4, 21 p. Southeast. For. Exp. Stn.

Fowler, William B.
1977. Adaptive speed and direction analyzer. U.S. Patent 4,011,752.

Morris, William G.
1934. Lightning storms and fires of the National Forests of Oregon and Washington. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. 27 p.

United States Water Resources Council.
1976. Guidelines for determining flood flow frequencies. Bull. 17, 197 p. Washington, D.C.

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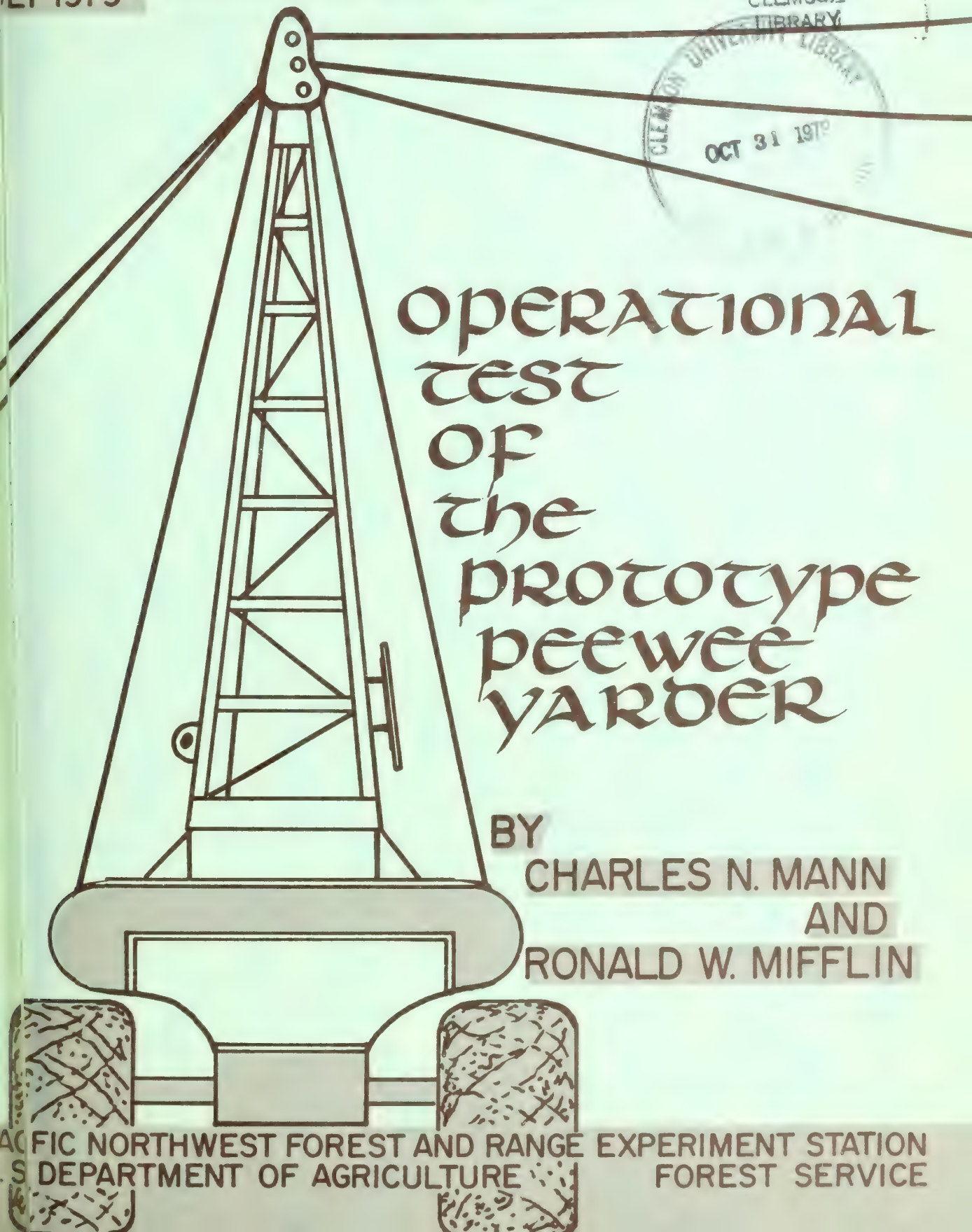
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OPERATIONAL TEST OF THE PROTOTYPE PEEWEE YARDER

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S DEPARTMENT OF AGRICULTURE FOREST SERVICE

ABSTRACT

An operational test of a small, prototype running skyline yarder was conducted early in 1978. Test results indicate that this yarder concept promises a low cost, high performance system for harvesting small logs where skyline methods are indicated. Timber harvest by thinning took place on 12 uphill and 2 downhill skyline roads, and clearcut harvesting was performed on 4 uphill skyline roads. Skyline roads were spaced about 46 meters (150 feet) apart and were up to 335 meters (1,100 feet) long. Delays caused by the yarder were insignificant. Production as high as 343 logs per day was achieved.

KEYWORDS: Logging equipment engineering, production studies(-forest operations, logging operations analysis/design, logging economics.

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Introduction

An operational test of the prototype peewee yarder was performed as part of a program to develop a system for harvesting small logs in areas where cable logging methods are required. The test was conducted at the University of Washington's experimental forest near Eatonville, Washington, by the Applied Physics Laboratory, a division of the University, on behalf of the Forest Engineering Unit of the Pacific Northwest Forest and Range Experiment Station. The objective of the test was to monitor the productivity of the system in a logging operation.

A thinning harvest was performed on 12 uphill and 2 downhill skyline roads over a 6-week period which began on February 22, 1978; and another week was spent in a clearcut area on 4 uphill skyline roads.

The need for commercial thinnings and the magnitude of the task were described by Lysons (1975). He also listed the systems criteria and technical requirements for suitable cable logging thinning equipment. Consideration of these criteria and requirements established the design of the peewee yarder.

Yarding System

The peewee yarder operates a running skyline system as shown in figure 1.

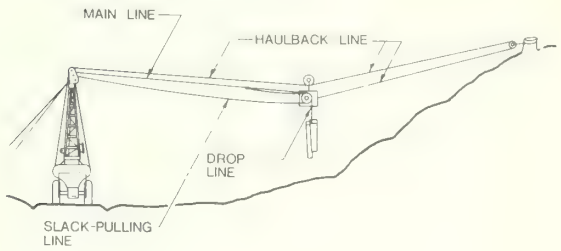


Figure 1.--Running skyline system.

The running skyline system was chosen because it provides a combination of features which are not available with other cable logging systems. These include: high mobility due to minimum rigging and small, light lines; versatility due to the ability to log uphill and downhill; and lateral yarding capability for partial cut operations which is provided by the slack-pulling carriage. General specifications for the yarder and yarding system are listed in table 1.

The prototype yarder (fig. 2) is mounted on a rubber-tired John Deere JD 640[1] cable skidder. Modifications to the skidder include removal of the winch and arch and installation of an oil cooler. The drum set is fastened to the skidder frame where the arch is normally located. A tower, with straw line and guyline drums, is mounted to the top of the drum set and can be lowered by hydraulic cylinders (fig. 3).

The drum set contains the main, slack-pulling, and haulback drums and the mechanism for interlocking the drums together. While details of interlocking drums are beyond the subject of this report, the peewee drum set is an advancement in interlock technology which

[1]Mention of products or trade names does not imply endorsement by the U.S. Department of Agriculture.

Table 1.--General specifications of peewee yarder prototype mounted on John Deere JD 640 cable skidder

Engine power	82 kilowatts (110 horsepower)
Span capability	366 meters (1,200 feet)
Lateral yarding capability	46 meters (150 feet)
Line speed:[1]	
Inhaul/outhaul	3.8 meters/second (750 feet/minute)
Lateral yarding	0.76 meters/second (150 feet/minute)
Line pull:[1]	
Main	27 000 newtons (6,000 pounds)
Slack-pulling	20 000 newtons (4,500 pounds)
Haulback (interlock tension)	40 000 newtons (9,000 pounds)
Drop line	40 000 newtons (9,000 pounds)
Overall dimensions:	
Height (tower erected)	11.3 meters (37 feet, 0 inches)
Height (tower lowered)	3.7 meters (12 feet, 2 inches)
Length (tower erected)	6.5 meters (21 feet, 4 inches)
Length (tower lowered)	9.4 meters (30 feet, 8 inches)
Width	3.06 meters (10 feet, 1/2 inch)
Weight	19 958 kilograms (44,000 pounds)

[1] At mid-drum diameter on 366-meter (1,200-foot) span.



Figure 2.--Prototype peewee yarder.



Figure 3.--Prototype peewee yarder with tower lowered.

simplifies control and reduces cost. For basic information on interlocked drum sets, refer to Mann (1977).

The yarder is driven hydraulically which eliminates the need for clutches and brakes. The three yarder control functions are operated by two levers. Speed and longitudinal direction of the carriage is controlled by one lever. The other lever is bidirectional and is used to raise and lower the carriage and control the drop line. All three control functions can be operated at the same time.

The operator's control station, enclosed by a protective screen, is located at the rear of the skidder. It is designed to allow the operator to unhook the turns, eliminating the need for a chaser. Additional levers at the control station operate the hydraulically driven guyline and strawline drums, hydraulic lift cylinders, and engine speed. An instrument box allows the operator to monitor skidder and yarder systems. A gage indicates interlock pressure which is a direct measure of haulback tension.

Two carriages were used during the test. The first was a conventional

mechanical slack-pulling carriage modified for 1/2-inch lines. It housed side-by-side sheaves for the drop line and the slack-pulling line. A problem was encountered as the slack-pulling line and drop line tended to twist or wrap around each other as they entered the carriage. Manual untwisting of the lines was often required to allow enough drop line to pass through the carriage to continue yarding. The twisting also resulted in kinked drop lines which had to be replaced.

Line twisting problems accounted for more delay time than any other problems encountered during the test. In an effort to reduce this problem, a second carriage (fig. 4) was designed by the Forest Engineering Research Unit. The primary features of this carriage are:

1. The sheaves are aligned in a plane, one below the other. This increases separation of the lines which reduces twisting and line wear.



Figure 4.--Slack-pulling carriage designed by the Forest Engineering Research Unit.

2. The lower carriage frame is hinged to allow the drop line sheave to separate from the pressure roller when a load is placed on the drop line. This prevents the drop line from twisting as it travels across the sheave.

Twisting problems were practically eliminated following the introduction of this carriage. Continuing design effort is expected to improve carriage operation and reduce carriage weight.

Test Site

Testing of the peewee yarder was conducted at the University of Washington's Pack Forest which is managed as an experimental forest.

Yarding tests took place in a 50-year-old stand of mixed Douglas-fir and red alder. The test site was on predominantly Site III land with very irregular terrain and stand density. All merchantable alder was removed wherever practical. The Douglas-fir thinning and salvage removed intermediate, overtopped, and damaged trees. In areas where Douglas-fir was predominant, approximately 120 cubic meters per hectare (17 cunits per acre) were removed from an estimated stand volume of 420 cubic meters per hectare (60 cunits per acre).

Logging Layout

The thinning operation was conducted in an area of about 14 hectares (35 acres). The yarder was set up on 12 uphill and 2 downhill skyline roads which extended approximately at right angles to an existing haul road. Skyline roads were spaced about 46 meters (150 feet) apart. Span lengths varied from 113 meters (370 feet) to 338 meters (1,108 feet), the average being 243 meters (797 feet). Average slope of the spans ranged from 31 percent downhill to 24 percent uphill.

Yarding corridors were initially flagged from selected tailholds. Narrow corridors were cleared to allow passage

of the carriage and log loads. Trees to be removed were felled in a herringbone pattern which allowed logs to be pulled directly into the corridor.

The final test phase was a clearcut harvest of about 1.6 hectares (4 acres) of predominantly alder. Yarding took place on four uphill skyline roads which were about 150 meters (500 feet) long.

Logging Operation

The yarder was positioned in the haul road and maneuvered to align the fixed headblock with each skyline corridor. Two winch-powered guylines were attached to anchor trees opposite the direction of yarding. An additional fixed-length safety guy, attached to the top of the tower, was usually rigged to a third anchor. Tailblocks were hung in guyed trees although this was not necessary on all roads. Tail trees were rigged on weekends when the schedule allowed.

The crew consisted of a yarder operator and two choker setters. A loader with operator was needed to keep the small landings clear and to load log trucks. Some landings were steep enough to require the loader to hold the logs while they were unhooked to prevent them from sliding down the slope.

Test Description

The operational test consisted of monitoring production and productive and non-productive times during the logging operation. Records were kept of cycle times, pieces per turn, and estimated log diameters throughout the test. Log lengths, cycle element times, and yarding distances were recorded during limited periods.

The original test plan specified obtaining timber volume removed by measuring the log truck loads. Difficulties with this approach took place during the test. At the end of the test, a large portion of the logs remained decked at the site due to unavailability of trucks and scheduling difficulties. An estimate of the number of truck loads left at the site was made, but adding these estimates with the loads removed did not account for the total number of pieces yarded.

A partial explanation for the volume discrepancy may be found in the fluctuations in the alder market. Before the test began, there was a market for the alder pulp logs. By the time logging started, alder was no longer in demand. During the test, the alder market was intermittent and the minimum acceptable log size kept changing. For this reason, there were many alder logs yarded which were later considered to be unmerchantable and were not trucked out or included in estimates of remaining loads. Also, due to the small log diameters, many were broken by the loader at the landing.

Test Results

An estimate of the volume production rate was made by determining an average log size from test data and multiplying it by the piece rate. The average log volume for the thinning operation was found to contain 0.38 cubic meters (13.5 cubic feet). This gives a production rate of 14 cubic meters (4.9 cunits) per hour of yarding time and 9.9 cubic meters (3.5 cunits) per hour of total time. In the clearcut, the average log contained 0.48 cubic meters (17 cubic feet). The resulting production rate is 20 cubic meters (7.1 cunits) per hour of yarding time and 14 cubic meters (5.0 cunits) per hour of total time.

The piece rate is more significant than the volume production rate for estimating the yarder's production capability in timber of a different log size. Log size has long been recognized as the most significant variable affecting yarding cost and production (Mifflin and Lysons 1978). A maximum of 4 chokers were used in this test which resulted in an average of 3.5 pieces per turn. Average loads were estimated to be less than half the capacity of the yarder. Therefore, in similar yarding situations, the piece rate could be expected to remain fairly constant

until the average log size approximately doubled with a similar increase in the volume production rate. From that point on, the number of pieces per turn would have to decrease.

Table 2 lists the time spent in various activities during the peewee test period. The time categories listed are defined as follows:

Actual yarding.--The time during which logs were being yarded. Short delays of 10 minutes or less are included.

Road change.--The time spent rigging tail trees, moving the yarder, and stringing lines between the last turn on one logging road and the first turn on the next one.

Scheduled maintenance.--The time prior to the start of actual yarding in the morning and after lunch for fueling, yarder warm-up, and checking levels of hydraulic fluids and lubricants.

Unscheduled maintenance (yarder).--The time spent correcting a yarder malfunction which caused a delay of more than 10 minutes.

Unscheduled maintenance (lines, etc.).--The time due to delays longer than 10 minutes caused by some part of the yarding system other than the yarder.

Miscellaneous delays.--The time due to interruptions in yarding of over 10 minutes caused by problems not related to the logging system.

Table 3 lists the daily yarding hours and the number of turns and pieces yarded during the test. The average number of turns per hour and pieces per hour for the thinning and clearcut are also shown.

Cycle element times and yarding distance measurements from two uphill skyline roads in the thinning operation were used to produce the plots shown in figures 5 and 6. Cycle time was divided into: (1) outhaul, which began when the carriage started moving away from the landing and ended when it reached the chokersetters; (2) hook, including lateral yarding; (3) inhaul, which began when the carriage started toward

Table 3--Daily production

Date	Hours yarded	Turns yarded	Pieces yarded	Turns per hour	Pieces per hour
			-Thinning-		
2/21	7.37	80	248	10.9	33.7
2/22	3.35	45	140	13.4	41.8
2/23	7.48	92	320	12.3	42.8
2/24	4.37	42	132	9.6	30.2
2/27	7.33	92	300	12.6	40.9
2/28	2.03	25	66	12.3	32.5
3/1	7.15	72	245	10.1	34.3
3/2	6.35	55	195	8.7	30.7
3/3	5.48	55	182	10.0	33.2
3/6	4.78	65	187	13.6	39.1
3/7	6.90	56	202	8.1	29.3
3/8	3.40	50	161	14.7	47.4
3/9	5.62	63	201	11.2	35.8
3/10	4.70	60	190	12.8	40.4
3/13	7.40	63	228	8.5	30.8
3/14	6.05	65	226	10.7	37.4
3/15	7.68	78	284	10.2	37.0
3/16	6.12	57	208	9.3	34.0
3/17	6.75	80	278	11.9	41.2
3/20	5.77	81	287	14.0	49.7
3/21	1.33	16	58	12.0	43.6
3/22	5.52	43	147	7.8	26.6
3/23	7.58	93	343	12.3	45.3
3/24	3.17	29	105	9.1	33.1
3/27	6.83	83	300	12.2	43.9
3/28	7.17	50	170	7.0	23.7
3/29	4.42	56	197	12.7	44.6
3/30	7.33	66	257	9.0	35.1
3/31	4.50	43	156	9.6	34.7
			Average - thinning	10.7	36.5
			-Clearcut-		
4/3	6.00	67	245	11.2	40.8
4/4	5.25	56	216	10.7	41.1
4/5	6.67	81	312	12.1	46.8
4/6	4.42	47	176	10.6	39.8
			Average - clearcut	11.1	42.0
			Average - combined	10.7	37.2

Table 2--Time summary

Activity	Thinning		Clearcut	
	Hours	Percent	Hours	Percent
Actual yarding	163.9	71.3	22.3	70.6
Road change[1/]	37.0	16.1	4.9	15.5
Scheduled maintenance	11.1	4.8	0.5	1.6
Unscheduled maintenance (yarder)	.7	.3	0	0
Unscheduled maintenance (lines, etc.)	6.9	3.0	2.8	8.9
Miscellaneous delays	10.3	4.5	1.1	3.5

[1/] An additional 98 man-hours were spent on rigging outside of normal working hours.

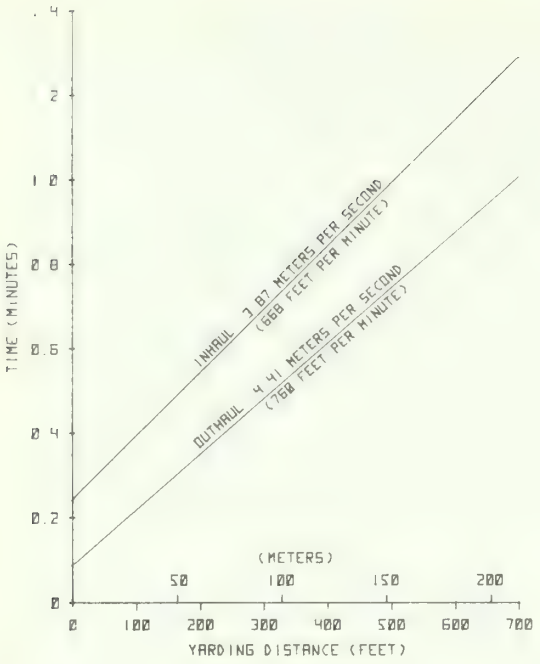


Figure 5.--Inhaul and outhaul times vs. distance.

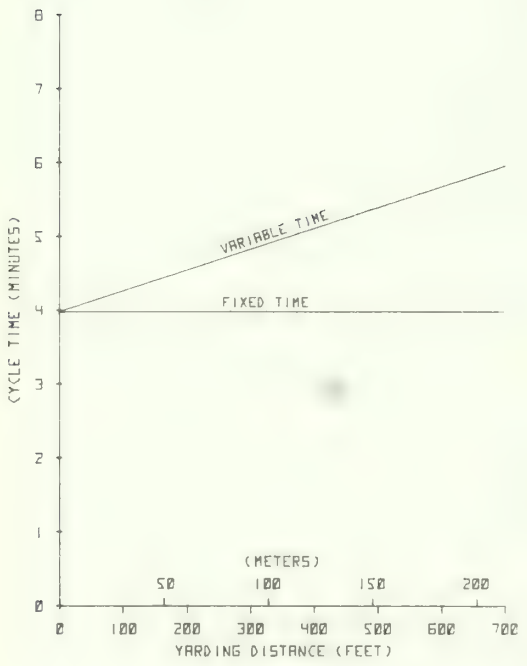


Figure 6.--Cycle time vs. yarding distance.

the landing and ended when the chokers went slack with the logs on the ground; and (4) unhook, which was the time between inhaul and outhaul.

Figure 5 shows the inhaul and outhaul time as a function of yarding distance. A linear regression analysis of the data resulted in the following equations:

Inhaul: $Y = .242 + .0049X$
$r = .910$
Outhaul: $Y = .088 + .0043X$
$r = .969$

where,
Y is time in minutes,
X is distance in meters, and
r is the coefficient of correlation.

The slopes represent an inhaul speed of 3.87 meters per second (668 feet per minute) and an outhaul speed of 4.41 meters per second (760 feet per minute).

Figure 6 presents a plot of cycle time versus yarding distance and was constructed according to procedures developed by Mifflin and Lysons (1978). The procedures were developed to provide cost prediction models for evaluating advanced logging systems. Cycle time is separated into fixed and variable times which can then be used to predict cycle times in different logging situations.

In figure 5, the inhaul and outhaul plots have a positive time value at zero yarding distance which indicates that some fixed time was included in these measurements. Therefore, total fixed time equals the inhaul and outhaul intercepts (time values at zero yarding distance) plus the average hook and unhook times.

Fixed time = intercepts + hook + unhook
= (.242 + .088) + 3.00 + .65 = 3.98 minutes

The variable time was obtained by summing the slopes of the inhaul and outhaul plots of figure 5.

Summary

The high production rate and lack of yarder-related delays clearly demonstrate the merits of a small running skyline yarding system for thinning where cable logging is desired. Crew size is reduced because the operator can act as the chaser, unhooking turns at the landing. Simplified controls reduce the training time required for an operator to become proficient. Location of the small yarder directly in the access road can result in minimal landing rerquirements.

The test also demonstrates the concept of a direct hydraulic drive, interlocked running skyline drum set. Problems with a prototype machine are the general rule in equipment development. The peewee yarder was an exception during the test. Problems with proven equipment such as the carriage and the radio signal system were the only significant causes of lost production time.

Production as high as 343 pieces per day were achieved during the test. Average loads were estimated to be less than half the capability of the yarder. This indicates that the production volume could have doubled given larger diameter logs and similar ground conditions.

Literature Cited

Lysons, Hilton H.
1975. Harvesting commercial thinnings on steep slopes, p. 154-156. *In* Global Forestry and the Western Role, Perm. Assoc. Comm. Proc., West. For. and Conserv. Assoc., Portland, Oreg.

Mann, Charles N.
1977. Running skyline systems for harvesting timber on steep terrain. Proc. Soc. Automotive Eng., Earthmoving Ind. Conf. Cent. Illinois Sec., Peoria, April 18-29, 1977. Tech. Pap. No. 770519. 6 p.

Mifflin, Ronald W., and Hilton H. Lysons.
1978. Skyline yarding cost estimating guide. USDA For. Serv. Res. Note PNW-325, 19 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

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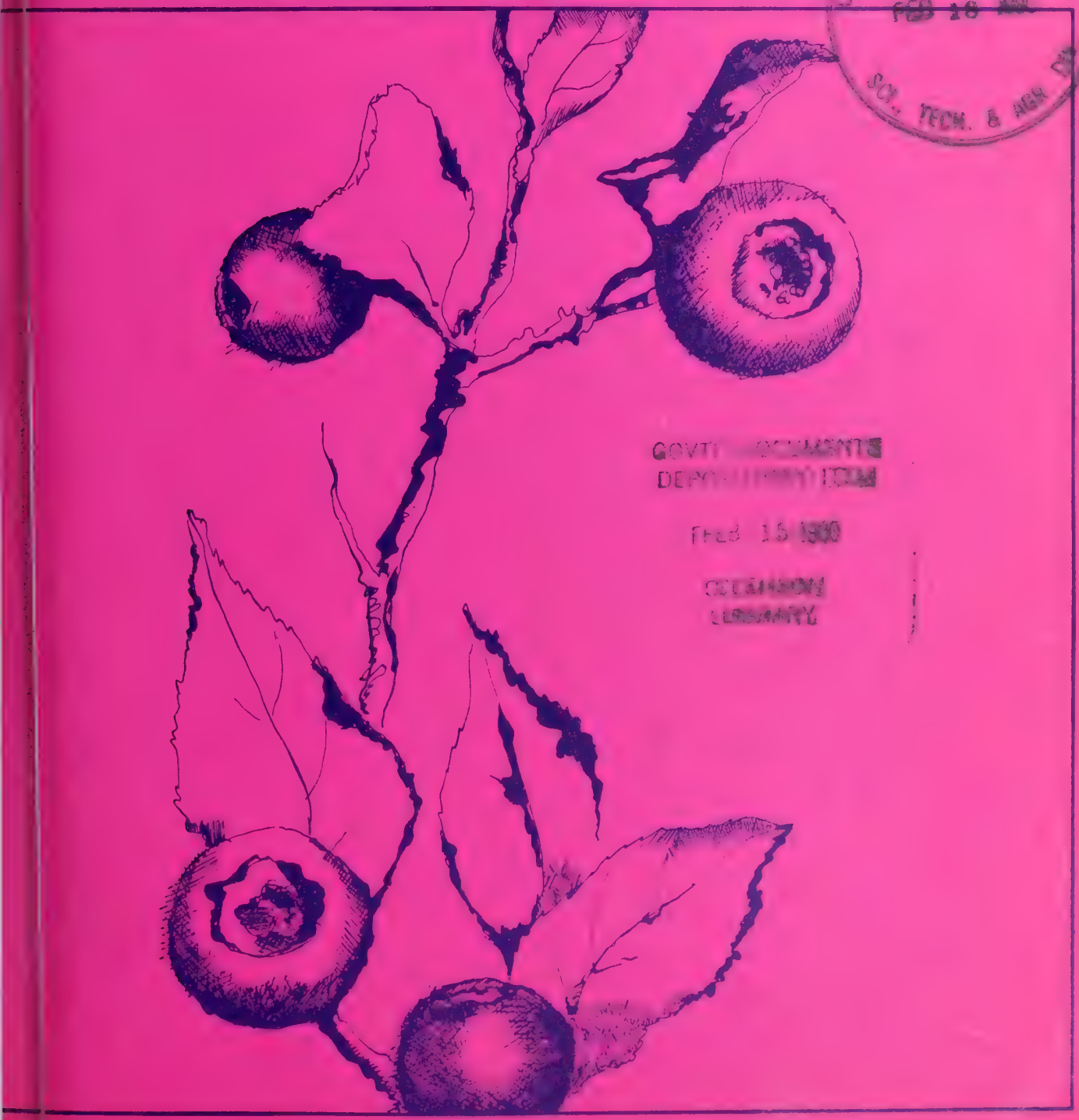
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Huckleberry Ecology and Management Research in the Pacific Northwest

Don Minore, Alan W. Smart and Michael E. Dubrasich

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ABSTRACT

Big huckleberry (*Vaccinium membranaceum* Dougl. ex Hook.) berry production is declining in many northwestern huckleberry fields as they are invaded by subalpine trees. Seeking ways to halt this invasion and increase berry production, the authors studied huckleberries in the Cascade Range of Oregon and Washington from 1972 through 1977. They developed methods of growing huckleberries in the laboratory, tested several methods of controlling competing vegetation in the field, and recorded the changes in plant species composition and huckleberry production that resulted from applying these methods. This illustrated report includes descriptions of the experiments performed, results, conclusions, and management recommendations. It is a summary of the huckleberry research accomplished by personnel of the Pacific Northwest Forest and Range Experiment Station during the 6-year study period.

KEYWORDS: Huckleberries, Vaccinium, succession, research.



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INTRODUCTION

For centuries before men learned to prevent and control them, wildfires periodically raced through northwestern forests. Often destroying the forests on large areas in catastrophic burns, these wildfires frequently created open, tree-free environments above 3,000 ft (914 m) that were suitable for the growth and development of wild huckleberries. Some of the resulting huckleberry fields were heavily used by Indians.

Indians apparently dried their huckleberries by placing them near campfires or slowly burning rotten logs ignited for that purpose. Some years, when dry conditions and high winds were favorable, these drying fires may have spread and reburned the berry fields. The Indians also may have deliberately set fires to reburn the heavily used fields during dry, windy periods. In any event, periodic fires kept trees out of many huckleberry fields and created new fields where postfire environmental conditions were favorable for huckleberry growth.

Twelve blueberry-like huckleberry species grow in Oregon and Washington (Minore 1972), and huckleberry fields occupy over 100,000 acres (40 469 ha) in these two states.[1/] Unfortunately, this acreage is dwindling. Most large wildfires have been effectively prevented or controlled in recent years, and Indian-set fires have not burned over the most heavily used, high-elevation, huckleberry fields for several generations. As a result, trees of low timber quality have been invading many high quality huckleberry fields (figs. 1 and 2). These trees eventually form dense subalpine forests that crowd and shade the shrubs, eventually eliminating huckleberry production.

Berry production is surprisingly high in some of the fields. We measured a yield of 100 gal per acre (935 l per ha) on one high quality huckleberry area in 1976. In 1977, when overall berry production tended to be poorer, another area produced 77 gal per acre (720 l per ha). Fresh huckleberries sold for $10.00-11.00 per gal ($2.64-2.90 per l) in 1977. Most berry pickers do not pick every berry on an area, but picking only half the berries would have produced economic yields of over $300 per acre ($741 per ha) on several areas sampled in 1977.

[1]Gerhart H. Nelson. Huckleberry management. 4 p. May 14, 1970. (Unpublished, on file at USDA Forest Service, Region 6, Portland, Oreg.)



Figure 1.--A portion of the Sawtooth huckleberry field near Mount Adams, Washington in 1938. Note snags and open aspect.



Figure 2.--The same area shown in figure 1, 34 years later. These two photographs, taken at the same point, illustrate the rapid invasion by trees of this highly productive huckleberry field. Subalpine forest will soon reduce berry production.



FIELD RESEARCH IN THE MOUNT ADAMS AREA

Economic yields do not adequately reflect the importance of the northwestern huckleberry resource, however, for the intangible values of fresh air, mountain scenery, and berry buckets they have filled themselves are far more important than market values to most huckleberry pickers. Many people pick berries just for fun. Over a thousand vehicles were tallied in one ranger district's berry fields during a single huckleberry-season weekend in 1971. On another district, 163,000 visitor-days were recorded in one heavily used field during 1969 (see footnote 1).

Considered either economically or recreationally, deterioration of the northwestern huckleberry resource is serious. Several factors are involved: natural succession in the absence of wildfires; huckleberry regeneration, growth, and berry production; meteorological effects; and the regeneration, growth, and competition of associated species. Seeking a better understanding of these factors, we studied huckleberries from 1972 through 1977. Field phenomena were investigated in two areas near Mount Adams, Washington, and Mount Hood, Oregon. We conducted laboratory and greenhouse studies at the USDA Forestry Sciences Laboratory in Corvallis, Oregon. This report is a summary of the research at all three locations during the 6-year study.

History

The huckleberry fields near Mount Adams have been heavily used by berry pickers for many years. Members of the expedition led by Captain George B. McClellan noted the extensive burned-over areas in this vicinity and found many Indians picking and drying berries there in 1853. One member recollected "a full tribe" and wrote "I never saw so many (Indians) and so many kinds of berries in all my life."[2/]

Eighty-one years later, in 1934, an animal exclosure was constructed to monitor the effects of grazing in the berry fields. Vegetation within the exclosure and on an adjacent unfenced plot was observed yearly until 1942. The Forest Service observers concluded that sheep benefited the berries by reducing vegetative competition and lightly browsing the huckleberry shrubs.[3/] In 1937, all trees were

[2]George Henry C. Hodges. Personal recollection. Page 146, Washington State Historical Society Publication. Volume 2, 1907 to 1914. (On file at USDA Forest Service Gifford Pinchot National Forest. Vancouver, Wash.)

[3]K. C. Langfield. Effect of grazing on huckleberry production. 2 p. December 9, 1942. (Unpublished, on file at Mount Adams Ranger District, Trout Lake, Wash.)

felled on 5 acres (2 ha) of berry field in the same Mount Adams area.[4] Later (1963), more trees were felled, and 6 acres were disked in an attempt to control vegetative competition.[5] Berry production was not measured on these felled or disked areas, but disking apparently stimulated rhizome sprouting. A huckleberry management plan was formulated for the Mount Adams huckleberry resource in 1968, but never implemented (see footnote 5).

Dr. Perry C. Crandall (Washington State University, personal communication, March 17, 1972) applied replicated herbicide treatments near Mount Adams in 1969. He found that Casaron, Simazine, Atrazine, and Paraquat were ineffective in selectively controlling vegetation competing with huckleberries. Crandall's huckleberry pruning trials (50 percent and 80 percent top removal) were also ineffective, damaging the huckleberry shrubs rather than improving them.

1972 Experiment

AREA DESCRIPTION

We established a vegetation control experiment 13 mi. (21 km) southwest of Mount Adams during the summer of 1972 in sec. 16, T. 7 N., R. 8 E. Located in a portion of the Sawtooth Huckleberry Field already invaded by subalpine forest, this experimental area is at an elevation of 4,000 ft. (1 219 m), with a gently sloping WSW aspect. Lodgepole pine, western white pine, subalpine fir, Douglas-fir, mountain hemlock, and Engelmann spruce comprise most of the forest canopy (see table 1, fig. 3).[6]

The 1972 experimental area occupies soil that is shallow, coarse-textured, gravelly, low in nutrients (table 2), and subject to erosion. Invading trees are short and poorly formed, often showing considerable snow damage. Snow packs usually are deep and long-lasting, and the growing season is cool and short.

[4]George A. Bright. Huckleberry release from reproduction. 3 p. September 24, 1937. Unpublished, on file at Mount Adams Ranger Station, Trout Lake, Wash.)

[5]Donald E. Wermlinger. Twin Buttes huckleberry management plan. 25 p. January 5, 1968. Unpublished, on file at Mount Adams Ranger Station, Trout Lake, Wash.)

[6]Table 1 lists scientific names for all plants mentioned in this report.

Table 1--Names of plants[1/]

Common name	Scientific name
Agoseris , orange	*Agoseris aurantiaca* Greene
Beadlily, Queencup	*Clintonia uniflora* (Schult.) Kunth
Beargrass	*Xerophyllum tenax* (Pursh) Nutt.
Blueberry, eastern lowbush	*Vaccinium angustifolium* Ait.
Bramble, dwarf	*Rubus lasiococcus* Gray
Bunchberry	*Cornus canadensis* L.
Cinquefoil, Drummond	*Potentilla drummondii* Lehm.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Everlasting, pearly	*Anaphalis margaritacea* (L.) B. & H.
Fescue, sheep	*Festuca ovina* L.
Fescue, western	*F. occidentalis* Walt.
Fir, grand	*Abies grandis* (Dougl.) Lindl.
Fir, noble	*A. procera* Rehder
Fir, Pacific silver	*A. amabilis* (Dougl.) Forbes
Fir, subalpine	*A. lasiocarpa* (Hook.) Nutt.
Fireweed	*Epilobium angustifolium* L.
Hawkweed, white	*Hieracium albiflorum* Hook.
Hemlock, mountain	*Tsuga mertensiana* (Bong.) Carr.
Hemlock, western	*T. heterophylla* (Raf.) Sarg.
Huckleberry, big	*Vaccinium membranaceum* Dougl. ex Hook.
Huckleberry, blue	*V. globulare* Rydb.
Huckleberry, blueleaf	*V. deliciosum* Piper
Huckleberry, evergreen	*V. ovatum* Pursh
Huckleberry, red	*V. parvifolium* Smith
Lupine	*Lupinus* spp.
Mountain-ash	*Sorbus* spp.
Oatgrass, timber	*Danthonia intermedia* Vasey
Phlox, pink annual	*Microsteris gracilis* (Hook.) Greene
Pine, lodgepole	*Pinus contorta* Dougl. ex Loud.
Pine, western white	*P. monticola* Dougl. ex D. Don
Pussytoes, rose	*Antennaria rosea* Greene
Redcedar, western	*Thuja plicata* Donn
Sedge	*Carex* spp.
Sorrel, sheep	*Rumex acetosella* L.
Spirea	*Spiraea* spp.
Spruce, Engelmann	*Picea engelmannii* Parry ex Engelm.
Strawberry, western wood	*Fragaria vesca* L.
Violet	*Viola* spp.
Wildrye, blue	*Elymus glaucus* Buckl.
Willow	*Salix* spp.
Willow-herb, alpine	*Epilobium alpinum* L.
Willow-herb, small flowered	*E. minutum* Lindl. ex Hook.
Woodrush, field	*Luzula campestris* (L.) DC.

[1/] Nomenclature follows Fernald (1950), Garrison et al. (1976), and Hitchcock and Cronquist (1973). Some of the common names were obtained from Peck (1961).



Figure 3.--A portion of the experimental area near Mount Adams before treatment. Note invading trees.

Table 2--Soil properties at the Mount Adams experimental area[1/]

Property	Depth (cm)[2/] 0-15	16-30	31-46
pH	5.6	5.6	5.8
Cation exchange capacity (meq/100 g)	13.19	13.10	11.66
Total nitrogen (percent)	.11	.07	.05
Phosphorus (pm)	14.00	6.00	3.00
Potassium (pm)	28.40	16.40	11.20
Calcium (meq/100 g)	1.04	.70	.39
Magnesium (meq/100 g)	.08	.07	.05
Sodium (meq/100 g)	.02	.02	.03
Boron (pm)	.22	.22	.20
Acetate extractable iron (pm)	42.00	53.00	168.00

[1/] Average values based upon analyses of 4 samples--1 for each of the randomly distributed control plots.

[2/] To obtain depth in inches, multiply by 0.394.

OBJECTIVES

The primary objective of this 1972 experiment was the development of a method that could be used to control competing species without reducing huckleberry[7]/ growth or berry production. Ideally, such a method would increase berry production by creating a more favorable environment for the plants. Secondary objectives included a study of plant succession after disturbance and assessments of the effects of sheep grazing on huckleberry growth and berry production and on forest regeneration.

EXPERIMENTAL DESIGN

We used a completely random experimental design in 1972, with five treatments replicated four times. The following treatments were randomly assigned to a grid of 20 plots (fig. 4): sheep grazing; cut and burn; burn; borax application; and control (no treatment). Each plot is 120 ft (37 m) square, occupying an area of 1/3 acre (0.14 ha).

[7]Throughout this report, "huckleberry" refers to Vaccinium membranaceum. Names of other Vaccinium species mentioned are given in table 1.

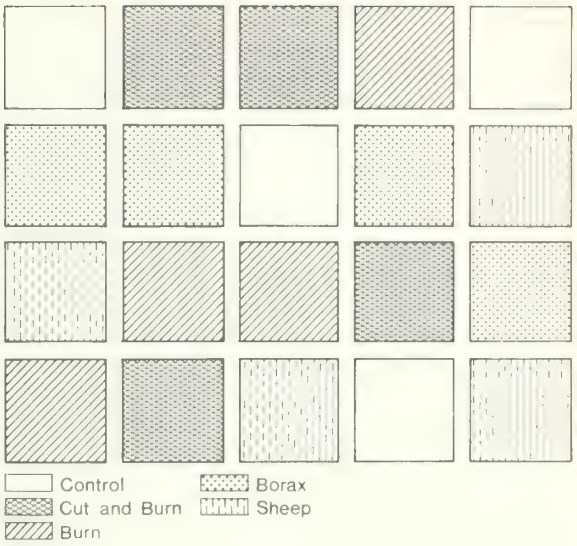


Figure 4.--1972 experimental plots near Mount Adams. Each 1/3-acre (0.14-ha) plot is 120 ft (37 m) square, with 10-ft (3-m) buffer strips between.

TREATMENTS

Sheep Grazing

We constructed a 3-ft (0.9-m) high woven wire fence around the entire experimental area and fenced all four sheep plots during July 1972. A cooperator provided 320 dry ewes. On August 22, eighty of these sheep were penned on each 1/3-acre (0.14-ha) sheep plot. They were confined on these small plots for 3 days, then returned to the cooperator. The resulting grazing intensity far exceeded anything that occurs during normal grazing operations, even exceeding the local intensity produced in bedding grounds. This deliberate

overgrazing was an attempt at controlling competing vegetation, but it also served as a severe test of possible sheep damage to the huckleberry resource. (Many huckleberry pickers claim that grazing damages the huckleberries; they strongly oppose allowing sheep in the berry fields.)

Cut and Burn

All trees on the four cut-and-burn plots were felled by chain saw during the second week in August 1972; cut trees remained where they had fallen. Firelines were constructed around each plot during the first week in September.

We attempted to burn during the second week in September. Drip torches and slash fuel were used to ignite the 1-month-old slash, but it was not dry enough to burn. An early autumn storm covered the experimental area with 4 in (10 cm) of snow on September 25. The snow melted by September 29, however, and snowmelt was followed by several days of warm, dry weather and strong east winds. When burning was attempted again October 3 to 7, a weather station 5 mi (8 km) away, at the same elevation, recorded 2:00 p.m. relative humidities averaging 35 percent, average maximum temperatures of 66° F (19° C), dry east winds averaging 7 mi/h (11 km/h), and 10 percent average fuel moisture (10-h lag).[8] This time we used a flamethrower and about 150 gal (568 l) of diesel oil. Although the resulting fire would not spread through the slash, all of the plots were burned by applying the flamethrower over the entire area. Fine fuels, herbaceous vegetation, and huckleberry leaves were consumed by the oil-fueled flame. Coarse fuels, duff, and huckleberry stems were blackened, but not consumed (fig. 5).

Burn

Burning previously untreated plots was even more difficult than burning the slash on cut-and-burn plots; little fuel was present under the uncut trees, and a fire could not be kindled or spread. Nevertheless, by using about 150 gal (568 l) of diesel oil and the flamethrower, we burned all four plots from October 3 to 7. Huckleberry shrubs, herbaceous vegetation, and lower tree branches were burned deliberately. Burning intensity was slightly less than that obtained on the slash-covered plots. Fine fuels, herbaceous vegetation, and huckleberry leaves were consumed, but coarse fuels, duff, and huckleberry stems were only blackened (fig. 6). A few huckleberry stems survived.

[8] As measured with fuel moisture sticks, the 10-h lag represents the moisture content in 1/4-1 in (0.6-2.5 cm) material.



Figure 5.--Cut-and-burn plot near Mount Adams, immediately after burn. October 1972.



Figure 6.--Burn plot near Mount Adams, immediately after burning in October 1972.

Borax Application

When borax was applied to eastern lowbush blueberry fields at the rate of 1 or 2 lb per 100 ft^2 (4.8 or 9.8 kg per 100 m^2), it killed or injured several weedy species without injuring the berry bushes (Smith, Hodgdon, and Eggert 1947). Although the eastern lowbush blueberry is quite different from our western huckleberry, we applied similar quantities of borax powder to four plots during the third week of September 1972. Dividing each plot into 49 equal areas, we scattered 5 lbs (2.27 kg) on each area--a total of 245 lb (111 kg) of borax per 1/3-acre (0.14-ha) plot. Borax is $Na_2B_4O_7.10H_2$ so the actual amount of boron applied was 27.8 lb (12.6 kg) per plot, or 83.3 lb/acre (93.4 kg/ha).

Control

All four control plots were inside the fence constructed to prevent indiscriminate grazing, but they received no other treatment.

DATA COLLECTION AND PROCESSING

Vegetation

We measured species composition and cover on all but the cut-and-burn plots in 1972, before treatment. (Cutting occurred before pretreatment vegetation could be measured on the cut-and-burn plots.) These measurements were repeated on all plots (including those cut and burned) in 1973, 1974, 1975, and 1977.

We used the line interception method described by Canfield (1941). Four 120-ft (37-m) lines were established at equal intervals on each plot. Measurements were taken along a tape stretched 3.3 ft (1 m) above the soil surface. Linear species coverage--first below and then above the tape--was recorded to the nearest 0.1 ft (3 cm) along the entire line each time. Thus, 480 ft (146 m) of line were measured on each of the 20 plots.

Except for grasses, linear measurements were converted to percentage cover for each plant genus. Linear grass measurements and total grass cover were recorded; grass species were identified, but separating percentage cover of individual grass genera and species proved to be impractical from the 1-m tape height. Dominance estimates were substituted for linear measurements of grass species. Sedges were recorded as *Carex* spp. Several other plant species were identified while blooming, but recorded as genera during cover measurements.

Berry Production

Huckleberry production was measured by picking and weighing the berries on 16 one-mil-acre (0.0004 ha) subplots in each treatment plot. These subplots were systematically located and permanently marked at equal intervals along the vegetation intercepts. The berries were picked in late August each year, combined on each plot, then weighed while fresh. All berries were picked and weighed on each of the 320 subplots (20 treatment plots) during 1972, 1973, 1974, 1975, and 1977. Random subsamples of ripe berries and of all berries harvested were then counted and weighed on each plot. The average weight of a ripe berry on that plot was then determined, as was the average weight of a harvested berry. (All berries, ripe and green, were harvested.) Harvested weight on each treatment plot was then converted to ripe weight by using the following equation:

$$\text{Ripe weight} = (\text{Harvested weight}) \times \left(\frac{\text{Average weight of a ripe berry}}{\text{Average weight of a harvested berry}}\right)$$

Statistical Analyses

Both vegetation and berry-production data were subjected to analyses of variance each year. Coverage of each plant species or species group and ripe berry weights were compared among treatments in these analyses. Where significant differences occurred, Scheffé (1959) multiple comparison tests were used to identify the treatments.

RESULTS

Overstory Vegetation

As expected, the cut-and-burn treatment completely eliminated all overstory competition. Burning alone was less effective, but it also reduced the overstory cover. The burning killed many trees immediately. Others were severely injured and died several years later (fig. 7). By 1977, total



Figure 7.--The same burn plot shown in figure 6, 5 years after burning. August 1977.

overstory canopy on the burn plots was significantly 9/ less than that on the control, borax, or sheep plots (table 3). The sheep and borax treatments did not significantly affect overstory canopy composition or cover. Overstory canopy results are graphically compared in figure 8.

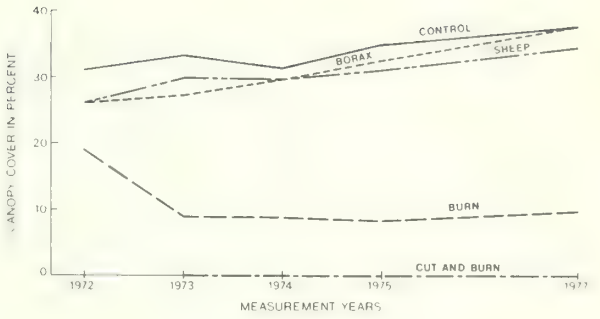


Figure 8.--Average overstory canopy at the Mount Adams experimental area. Treatments were applied between the 1972 and 1973 measurements.

9/Unless otherwise noted in this report, significance refers to statistical significance at P< 0.05 as indicated by Scheffé tests.

Table 3—Average overstory cover (percent) on the Mount Adams experimental area[1]

Year and treatment	Lodgepole pine	Western white pine	Douglas-fir	Subalpine fir2/	Pacific silver fir2/	Noble fir2/	Engelmann spruce2/	Mountain hemlock	Western hemlock	Willow	Total overstory cover
1972 (before treatment):											
Control	22.1	5.3	2.1	0.3	1.2	0	[illegible]	0.1	[illegible]	[illegible]	31.1
Borax	16.3	[illegible]	[illegible]	0.1	[illegible]	0	0.3	[illegible]	0	0.2	26.1
Sheep	16.8	[illegible]	2.7	0	[illegible]	0.6	0	0.1	[illegible]	0.6	26.1
Burn	11.8	2.6	[illegible]	1.3	[illegible]	0	[illegible]	1.7	0	1.0	[illegible]
Cut and burn 3/	--	--	--	--	--	--	--	--	--	--	--
1973:											
Control	22.2	5.8	3.1	0.3	1.1	0	0	0.4	0	0.5	33.4
Borax	17.0	4.0	5.7	0.1	0	0	0.3	0	0	0.2	27.3
Sheep	19.2	5.6	2.6	0	0	0.7	0	0.1	0	1.7	29.9
Burn	7.9	0.6	0.1	0	0	0	0.1	0.5	[illegible]	0	[illegible]
Cut and burn	0	0	0	0	[illegible]	[illegible]	0	[illegible]	[illegible]	0	0
1974:											
Control	20.[illegible]	6.6	3.6	0.3	1.2	0	0	[illegible]	0	0.5	[illegible]
Borax	18.6	4.6	5.9	0.2	[illegible]	0	0.3	0	0	0.2	29.8
Sheep	19.[illegible]	5.2	2.8	0	0	0.8	0.2	0.1	0	[illegible]	29.6
Burn	8.4	0	0	0	0	0	0.2	0.3	[illegible]	0	8.9
Cut and burn	0	0	0	0	0	0	0	0	[illegible]	0	0
1975:											
Control	23.8	[illegible]	3.2	0.3	1.3	0	0	0.4	[illegible]	0.2	35.0
Borax	21.4	5.0	5.5	[illegible]	0	0	0.4	0	0	0.1	[illegible]
Sheep	20.9	5.7	3.0	0	0	0.7	0	0	0	0.9	31.2
Burn	8.5	0	0	0	0	0	0.1	0	0	0	[illegible]
Cut and burn	0	0	0	0	0	0	0	[illegible]	0	0	
1977:											
Control	24.[illegible]	[illegible]	[illegible]	0.3	1.3	0	0	0.6	0.3	0.6	37.7
Borax	24.4	6.1	6.1	0.6	[illegible]	0	0.5	0	0	0.1	[illegible]
Sheep	24.1	[illegible]	[illegible]	0.1	0	0.7	0.5	0.6	0.1	0.9	[illegible]
Burn	8.6	0.2	0	0	0	0	0.5	0.5	0	[illegible]	9.8
Cut and burn	0	0	0	0	0	[illegible]	0	0	0	0	0

1/ Each average represents four treatment plots. Averages within a common bracket are not significantly different (Scheffé tests were not significant at P<0.05).

2/ Absence on most treatment replications made statistical analyses impractical.

3/ No vegetation data were collected on the cut-and-burn treatment plots in 1972.

Understory Vegetation

Burning significantly affected understory cover and composition. Huckleberry and beargrass cover percentages initially dropped on the burned plots, then recovered. By 1977, no significant differences occurred among treatments for these two species (table 4). Understory trees did not recover as quickly, and the understory cover of lodgepole pine, western white pine, subalpine fir, and Douglas-fir was lower on burned than on unburned plots in 1977.

Grasses were not significantly affected at first, but they began to increase 2 years after being burned. By 1977 (5 years after treatment), grass cover was significantly greater on the burned plots than it was on unburned plots. Species composition was also affected. The dominant grass species on the burned plots in 1977 was timber oatgrass; dominant grasses on the unburned plots were blue wildrye, western fescue, and sheep fescue. Sedges, pearly everlasting, rose pussytoes, sheep sorrel, and fireweed all responded like the grasses--no significant differences were recorded for 1 or 2 years after burning, but by 1977 they were significantly more abundant on the burned plots. Few significant differences appeared among burning treatments; burning with and without slash had similar effects on the understory. These effects are illustrated in figures 7 and 9.

Understory vegetation on the control, sheep, and borax plots was not significantly affected by the 1972 treatments--with one exception. Pink annual phlox, a tiny herb, invaded the sheep plots 1 year after grazing to create a significantly greater cover there. By 1974 this seral species began to fade away on the sheep plots, and by 1977 it was found only where burning had occurred.

Berry Production

Both burning treatments significantly reduced huckleberry production on the Mount Adams experimental area (table 5). The huckleberry plants sprouted during the next growing season (fig. 10), but no flowers or berries were produced on these sprouts until 1975--3 years after the burning treatments were applied. Five years after treatment, a few berries occurred on the burned plots, but the bushes still had not completely recovered. Control plots produced 7 times as many berries as the burn plots and almost 300 times as many berries as the cut-and-burn plots in 1977. Although some of these 1977 differences in berry production were associated with differences in overstory protection from a severe local hailstorm, very few flowers or berries were present on the burned plots before or after the August storm.

Overgrazing by sheep reduced berry production for 2 years, but increased it during the 3d year after treatment. The borax treatment had little effect on berry production.

Table #4 which should appear on pages 17 & 18 will be found at back of book.

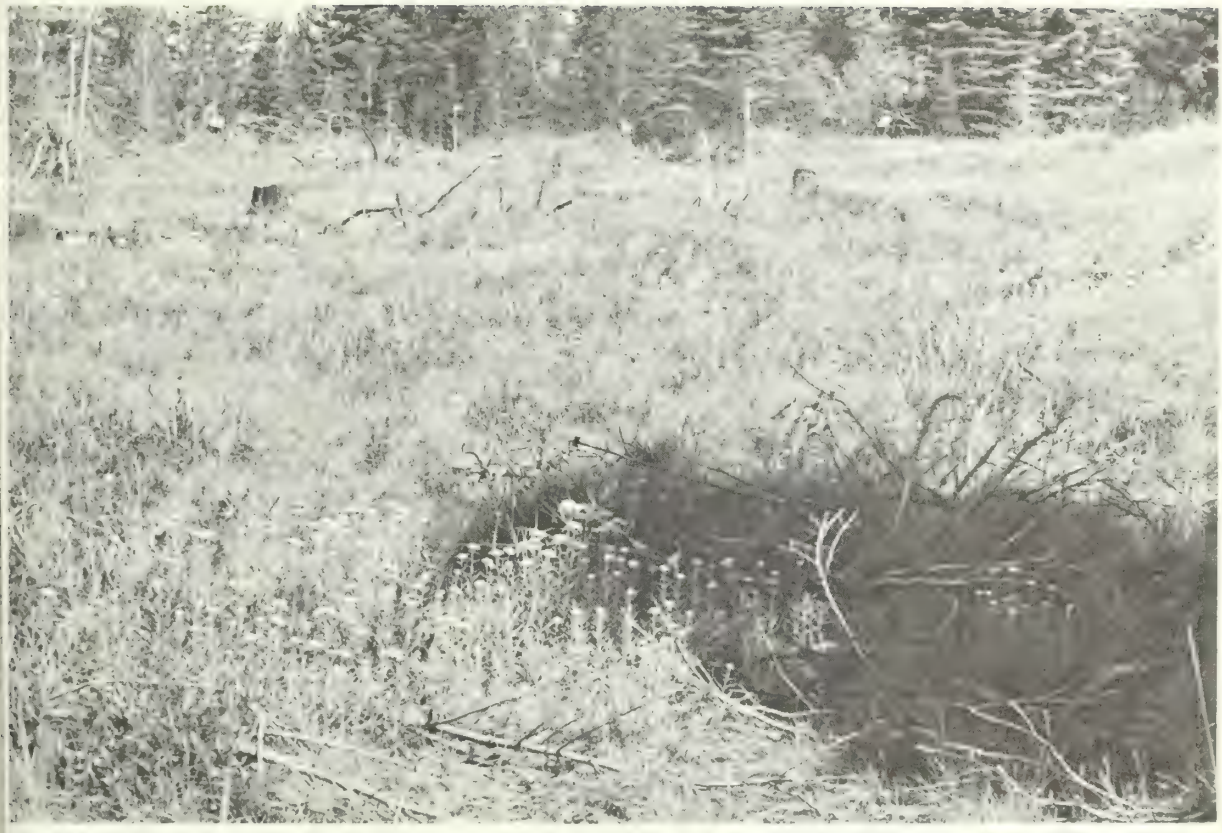


Figure 9.--The same cut-and-burn plot shown in figure 5, 5 years after burning (1977). Note grass cover and sprouting huckleberries.

Table 5 --Average berry production on the Mount Adams experimental area[1/]

Treatment	Berry production by year				
	1972[2/]	1973[3/]	1974	1975	1977[5/]
	Kilograms per hectare[4/]				
Control	99.30	0	132.15	137.53	35.06
Borax	61.43	0	43.22	69.07	44.98
Sheep	81.24	0	38.03	167.03	41.00
Burn	83.01	0	0.03	1.81	4.90
Cut and burn	--	0	0	0.27	0.15

1/ Each average represents 4 treatment plots. Averages within a common bracket are not significantly different (Scheffé tests were not significant at $P<0.05$).

2/ Berries were picked before the treatments were applied. No production data were collected on the cut-and-burn treatment plots.

3/ Unusual cold and very little snow during the 1972-73 winter, followed by severe spring frosts, destroyed the 1973 berry crop.

4/ To obtain pounds per acre, multiply by 0.8922.

5/ A severe August hailstorm destroyed most of the berries on the experimental area.



Figure 10.--Sprouting huckleberry shrub on a Mount Adams cut-and-burn plot, 1 year after treatment. Note old shoots killed by the fire. August 1973.

Miscellaneous Treatment Effects

Although the borax treatment produced no statistically significant differences in overstory cover, understory cover, or berry production, it did affect vegetation. Conifer needles developed brown tips during the spring of 1973. In the fall, the new foliage on subalpine firs treated with borax was blue-green and seemed unusually vigorous. Beargrass plants were damanged slightly by the borax; they developed abnormal inflorescences and produced few seeds in 1973. Furthermore, average beargrass cover on the borax plots declined after treatment. It equaled the control cover before treatment in 1972, but was less than 60 percent of control cover in 1977 (table 4). Unlike the sudden decline and subsequent recovery after burning of beargrass, its slow decline on borax plots seems to be continuing.

Intensive overgrazing by sheep in 1972 did not significantly affect the cover of forest tree species. It did significantly reduce the number and average growth of tree seedlings on the sheep plots (table 6). Terminal bud nipping and trampling by the crowded, confined sheep seem to have been responsible. The sheep also added an estimated 2,000 lb of manure/acre (367 kg/ha) to the overgrazed plots.

Combustion of flamethrower oil probably was not complete when the burn and cut-and-burn plots were treated in 1972. Some contamination of the soil probably occurred from the 300 gal (1 136 l) of diesel oil used in burning the 2.7 acres (1.1 ha) occupied by these plots.

CONCLUSIONS

None of the four treatments successfully controlled competing species without damaging the huckleberries. Those treatments that controlled the competition (burning, cutting and burning) also reduced huckleberry production. Those that did not damage huckleberry (borax, sheep grazing) did not control competing species.

Sheep grazing did not damage the huckleberries. Although some browsing of the berry bushes occurred, this mechanical influence was more than offset by the nitrogen added as sheep manure. The damage to conifer seedlings (table 6) that resulted from overgrazing the sheep plots probably would be less severe under normal grazing practices.

Table 6 --Average tree seedling density and growth on sheep and control plots at the Mount Adams experimental area[1/]

Species	Seedlings per ha[2/] in 1976		Avg 1973 growth		Avg 1975 growth	
	Sheep plots	Control plots	Sheep plots	Control plots	Sheep plots	Control plots
	Number		Centimeters[3/]			
Lodgepole pine	5,752	12,046	4.9	7.2	6.0	6.3
Western white pine	2,179	2,832	4.9	8.2	4.8	6.5
Subalpine fir	1,905	2,090	3.3	5.1	4.1	4.8
Pacific silver fir	0	1,529	--	3.5	--	3.5
Grand fir	46	139	0	3.0	3.0	4.3
Noble fir	0	46	--	4.0	--	15.0
Douglas-fir	324	1,158	6.4	5.4	7.7	6.0
Mountain hemlock	46	185	2.0	7.2	6.0	11.2
Englemann spruce	139	46	1.3	12.0	1.3	16.0
All species	10,391	20,071	4.6	6.7	5.4	6.0

1/ Based on sixteen 12.5 m^2 (134.6 ft^2) circular samples systematically located on each of the 8 plots (4 sheep plots and 4 control plots). Significant ($P<0.05$) differences are underlined.

2/ To obtain seedlings per acre, multiply by 0.405.

3/ To obtain growth in inches, multiply by 0.394.

Recovery of the huckleberry bushes after fire seemed to be slow and several competing species appeared to recover faster. Burning was difficult and large quantities of diesel oil were applied, which may have influenced our results. These results should be compared with those obtained in similar burning experiments. Burning eastern lowbush blueberry (Black 1963, Smith and Hilton 1971) is not comparable, however, for the morphology and physiology of this eastern species are very different from the morphology and physiology of big huckleberry. Differences also occur among the western *Vaccinium* species, so conclusions about *V. membranaceum* should be based on *V. membranaceum* experiments.

Additional Mount Adams Field Research

Although our primary emphasis was on control of competing vegetation in the Mount Adams area, several other aspects of the huckleberry problem were investigated in smaller, previously published field studies. When the rhizome system and root structure of big huckleberry were investigated by hydraulic excavation (Minore 1975b), numerous robust rhizomes were found 8-30 cm (3-12 in) below the soil surface. The soluble solid contents of shaded and exposed huckleberry fruits sampled throughout one berry-picking season showed no significant exposure differences, but the berries were sweetest after beargrass began shedding seeds (Minore and Smart 1975). Finally, high huckleberry abundance was related to an optimum soil pH of 5.5 and the presence of seven associated plant species in a study of huckleberry environments (Minore and Dubrasich 1978).



FIELD RESEARCH IN THE MOUNT HOOD AREA

Area Description

Seven miles (11 km) southwest of Mount Hood, at an elevation of 4,800 feet (1 463 m), we established three field experiments in a uniform area where competing species are inhibiting huckleberry production. All three are in SE1/4, NW1/4 sec. 10, T. 4 S, R. 8 E.; and all are on gently sloping western aspects. A dense young conifer forest now occupies the site (fig. 11), but vegetatively vigorous huckleberry shrubs persist in the understory without producing many berries. Average overstory composition is 86 percent lodgepole pine, 7 percent noble fir, 4 percent Douglas-fir, 2 percent mountain hemlock, and 1 percent composed of scattered western white pine, subalpine fir, grand fir, western hemlock, Engelmann spruce, and western redcedar.



Figure 11.--Dense young conifer forest at the Mount Hood experimental area. There are 5,800 trees per acre (14,332 trees per ha) in the stand (55% are taller than 4.5 ft (1.4 m), 45% are seedlings). Big huckleberry is abundant in the understory, but berry production is poor.

Although its elevation is greater, the Mount Hood experimental area is warmer than the Mount Adams area during summer. Winter snow packs remain there longer than at Mount Admas, however, and huckleberry development (bud burst, blooming, berry ripening) is later at Mount Hood. On July 9, 1974, we had to use a toboggan to transport equipment over 2 mi (3.2 km) of snow-covered road, and 3 ft (0.9 m) of snow still covered portions of the access road on July 23.

Soil in the Mount Hood experimental area is shallow and rocky, but less subject to erosion than the soil encountered in the 1972 Mount Adams experiment. Like the Mount Adams soil, it is low in nutrients (table 7). Nevertheless, analyses of variance indicated that cation exchange capacity and contents of potassium, sodium, and boron are significantly higher in the Mount Hood soil than in the Mount Adams soil. Phosphorus and acetate-extractable iron are lower.

Bulldoze-And-Burn Experiment

OBJECTIVES

To test the effectiveness of mechanized overstory removal and subsequent slash burning for control of competing vegetation in the huckleberry fields, we conducted a bulldoze-and-burn to answer several questions: Does bulldozing provide suitable slash fuel for burning upper elevation huckleberry fields? If so, does it provide this fuel at less cost than tree-cutting with chain saws? Does the bulldoze-and-burn treatment seriously reduce huckleberry growth or berry production?

Table 7--Soil properties at the Mount Hood experimental area[1/]

Property	Depth in centimeters[2/]		
	0-15	16-30	31-46
pH	5.30	5.70	5.50
Cation exchange capacity (meq/100 g)	23.39	20.00	26.10
Total nitrogen (percent)	0.16	0.11	0.08
Phosphorus (pm)	4.90	6.00	6.40
Potassium (pm)	75.00	90.00	114.00
Calcium (meq/100 g)	0.69	0.29	0.38
Magnesium (meq/100 g)	0.12	0.07	0.07
Sodium (meq/100 g)	0.13	0.16	0.16
Boron (pm)	0.32	0.30	0.28
Acetate extractable iron (pm)	47.10	18.70	25.90

1/ Average values based upon analyses of 4 samples--1 for each of the randomly distributed control plots.

2/ To obtain depth in inches, multiply by 0.394.

EXPERIMENTAL DESIGN

We treated one plot in each of six pairs; the other, randomly located plot was used an an untreated control (fig. 12). Control plots are 1/3 acre (0.14 ha); adjacent treated plots are the same size, with an additional 30-ft (9-m) buffer strip that includes a tractor-built fireline.

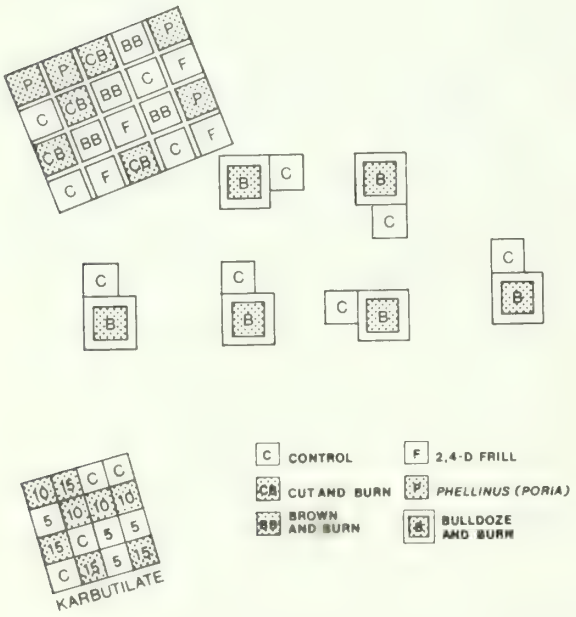


Figure 12.--The Mount Hood experimental area showing the paired-plot bulldoze-and-burn experiment (center), the Karbutilate plots (lower left), and the grid plots (upper left). Karbutilate plot numbers indicate pounds of active ingredient per acre.

TREATMENT

A Caterpillar D6C tractor with 12-ft angle blade was used to push over all trees on each of the six treated plots on October 23 and 24, 1973. Trees larger than 14 in (36 cm) d.b.h. were difficult to uproot or break off. Those smaller than 4 in (10 cm) d.b.h. tended to spring back after the blade went over them. Except where buried by slash or disturbed by uprooted trees, huckleberry shrubs were not damaged by the tractor. After transportation charges were deducted, the bulldozing cost $34 per acre ($84 per ha).

Slash created by the bulldozing was burned the following summer, early in the evening on August 26, 1974. Eight miles (13 km) away and 350 ft (107 m) lower, a weather station recorded a 2:00 p.m. relative humidity of 23 percent, a maximum temperature of 84° F (29° C), northwest winds of 6 mi/h (10 km/h), and a 10-h lag fuel moisture of 7 percent (see footnote 8) for that date. Cooperating personnel from the Zig Zag Ranger District, Mount Hood National Forest, used drip torches to ignite each plot. No contamination with fuel oil occurred. The slash burned well, but the fire did not spread into areas without slash. Small patches (less than 10 percent of the area treated) remained unburned. Most huckleberry shoots were blackened, but not consumed.

DATA COLLECTION AND PROCESSING

Vegetation data were collected on each bulldoze-and-burn plot in 1975 and 1977 by the techniques used at Mount Adams. Huckleberry and total overstory cover were tallied along four 120-ft (37-m) lines established on each plot. Competing understory species were not tallied.

Sixteen 1-milacre (0.0004 ha) subplots were established at equal intervals on each plot. Equal numbers of these subplots were randomly chosen on each plot in 1975 and 1977, and the berries on the chosen subplots were picked and weighed. Picked weights were converted to ripe weights by using the procedure described earlier.

Ripe berry weights, huckleberry cover, and total overstory canopy cover on the treated and control plots were compared by analyses of variance in 1975 and 1977.

RESULTS

The bulldoze-and-burn treatment eliminated dense overstory competition. The huckleberry understory was severely damaged by the burn, however, and huckleberry cover and berry production had not recovered to control levels 3 years after treatment (table 8). Huckleberry shrubs sprouted vigorously (fig. 13), but they produced very few berries.

CONCLUSIONS

Bulldozing provided suitable slash fuel for burning upper elevation huckleberry fields if the slash was allowed to dry for 1 year. It provided this fuel at less cost than tree-cutting with chain saws. The bulldoze-and-burn treatment effectively eliminated competing vegetation, but burning the slash seriously damaged huckleberry shrubs and reduced berry production for at least 3 years. Bulldozed sites look unattractive; bulldozing should not be done in scenic areas or where soil erosion is a problem.

Karbutilate Experiment

OBJECTIVE

Researchers in the Coast Ranges of Oregon and Washington observed that karbutilate killed most plant species, but had little effect on evergreen huckleberry and red huckleberry. Our objective was to determine if it could be used to kill competing plant species in Cascade Range huckleberry fields without affecting big huckleberry.

EXPERIMENTAL DESIGN

Four treatments were replicated four times in a completely random experiment. One-tenth-acre (0.04 ha) plots were used in a four-by-four grid (fig. 12). The following treatments were randomly assigned to these plots: 5 lb karbutilate/acre (5.6 kg/ha); 10 lb karbutilate/acre (11.2 kg/ha); 15 lb karbutilate/acre (16.8 kg/ha); and control (no treatment).

Table 8--Average overstory cover, huckleberry cover, and berry production on the Mount Hood bulldoze-and-burn experimental plots[1/]

	1975		1977	
	Control plots	Bulldoze-and-burn plots	Control plots	Bulldoze-and-burn plots
Overstory cover (percent)	45.30	0.20	50.60	0.20
Huckleberry cover (percent)	33.00	6.00	35.20	9.40
Berry production (kg per ha)[2/]	94.85	10.14	66.73	7.89

[1/] All control vs. bulldoze-and-burn differences are statistically significant ($P<0.05$).

[2/] To obtain pounds per acre, multiply by 0.8927.



Figure 13.--Three-year-old huckleberry shoots on a bulldoze-and-burn plot near Mount Hood. They are not producing berries.

TREATMENTS

The active ingredient in Tandex[10] is karbutilate (*m*-(3,3-dimethylureido) phenyl *tert*-butylcarbamate). It is often used as a soil sterilant. Mammalian toxicity is very low. We applied a granular form of the chemical (Tandex 10 G) in late June 1975, by uniformly spreading measured amounts on treated plots as the last snow was melting. We were extremely careful to secure an even distribution of the chemical and expended about 8 man-hours per acre (20 man-hours per ha). Control plots were located and marked, but they received no other treatment.

DATA COLLECTION AND PROCESSING

Overstory and understory cover were recorded in both 1976 and 1977 along three lines established on each of the 16 plots. As in the other huckleberry experiments, the resulting linear measurements were converted to percentage cover for each species. Cover percentages were then subjected to analyses of variance. Where significant differences occurred, Scheffé multiple comparison tests were used to identify the treatments involved. Berry production was observed, but not measured on the treated plots.

[10]Mention of companies or products does not constitute an endorsement by the U.S. Department of Agriculture.

RESULTS

The karbutilate applications produced no immediate results, but huckleberry leaves began to turn brown 1 month later. By late autumn 1975, a few of the overstory trees also began to show herbicide damage. One year later, effects of the herbicide were evident (fig. 14). The two heaviest applications

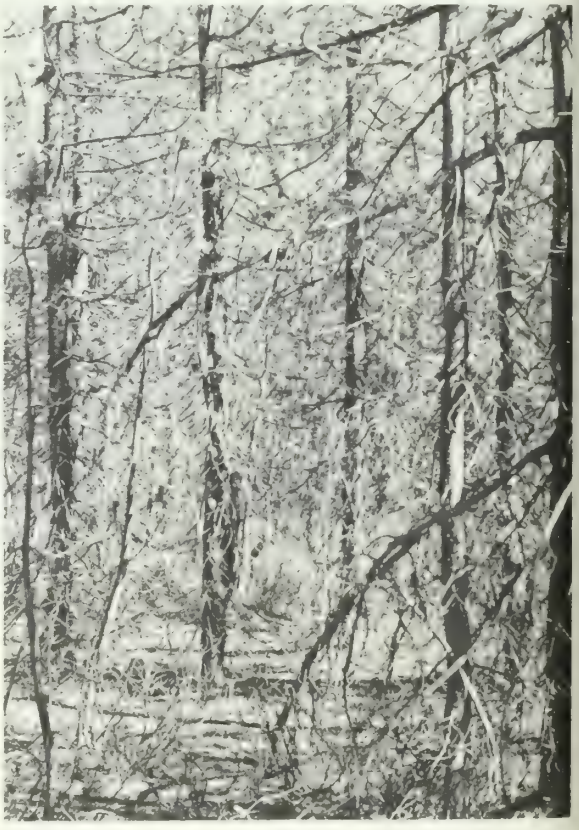


Figure 14.--A karbutilate plot 15 months after treatment with 15 lb of karbutilate per acre (16.8 kg/ha). The trees and huckleberry shoots are dead. September 1976.

Table 9—Average vegetative cover in percent on plots treated with karbutilate[1]

Year and treatment	Overstory[2]				Understory[2]						
	Lodgepole pine	Douglas fir	Noble fir	All species	Big huckleberry	Beargrass	Dwarf bramble	Pearly everlasting	Violet	Lodgepole pine	Total huckleberry competition
1976:											
Control	53.5	3.6	2.6	61.1	22.6	10.5	4.7	1.9	0.4	1.6	24.0
5 lb/acre (5.6 kg/ha)	34.6	7.2	1.9	46.1	9.8	8.1	4.3	0.7	0.9	1.0	18.8
10 lb/acre (11.2 kg/ha)	7.3	4.4	1.4	12.0	2.1	8.0	2.4	0.1	0.2	0.6	11.9
15 lb/acre (16.8 kg/ha)	3.9	3.6	3.3	9.0	2.4	9.5	1.0	0.1	0.4	0.5	13.0
1977:											
Control	49.4	4.0	2.9	58.4	30.2	7.6	6.6	2.2	0.5	3.3	23.6
5 lbs/acre (5.6 kg/ha)	28.8	5.6	3.5	38.5	22.5	5.7	4.9	0.8	1.0	1.4	17.8
10 lb/acre (11.2 kg/ha)	2.3	5.6	0	8.6	8.7	7.5	5.3	0.3	0.4	0.7	15.8
15 lb/acre (16.8 kg/ha)	1.5	3.9	0.2	5.6	5.1	8.6	2.7	0.1	0.9	0.2	13.5

[1] Each average represents 4 treatment plots. Averages within a common bracket are not significantly different (Scheffé tests were not significant at $P<0.05$).

[2] Only major species are listed individually, but all are included in the "all species" and "total huckleberry competition" columns.

could be identified on the ground by amount of vegetation damaged. Indeed, most plants (including huckleberry shoots) were dead. The 5-lb/acre (5.6-kg/ha) treatment produced significantly less damage (table 9); many of the overstory trees and huckleberry shoots were not killed.

Lodgepole pine was damaged more than noble fir by the herbicide, and noble fir was damaged more than Douglas-fir. We noted that karbutilate killed all of the conifer species from the bottom up. (When affected by 2,4-D, they die from the top down). Huckleberry shrubs appear to be slowly recovering from the treatments. Some of the damaged shoots bear a few green leaves, and some rhizomes are sprouting. Nevertheless, treated plots produced few berries in 1977, and many brown, curled leaves or bare huckleberry branches remained.

CONCLUSIONS

Karbutilate nearly eliminated competing vegetation in a huckleberry field when applied at 10-15 lb/acre (11.2-16.8 kg/ha). Unfortunately, it also nearly eliminated huckleberry. Lesser quantities of karbutilate were less effective in reducing competition and less damaging to huckleberry.

Five-Treatment Grid

OBJECTIVE

Like the 1972 experiment at Mount Adams, this Mount Hood experiment had as its objective the development of a method of controlling vegetation that could be used against competing species without reducing huckleberry growth or berry production. A successful method should increase berry production.

EXPERIMENTAL DESIGN

We duplicated the completely random experimental design used in the 1972 experiment at Mount Adams for this five-treatment, four replication grid, but applied different treatments (fig. 12): cut and burn; brown and burn; 2,4-D frill; *phellinus (Poria)* inoculation; and control (no treatment). As at Mount Adams, each grid plot is 120-ft (37-m) square, occupying an area of 1/3 acre (0.14 ha).

TREATMENTS

Cut and Burn

With chain saws, we cut all of the overstory trees on the four cut-and-burn plots in September 1973. The operation required about 18 man-hours per acre (44 man-hours per ha). The resulting slash was left in place, and firelines were built around each plot.

The 11-month-old slash was burned by Zig Zag Ranger District personnel late in the afternoon on August 26, 1974. Meteorological conditions for that date are recorded elsewhere (see bulldoze-and-burn experiment). Relative humidity was 30 percent and the temperature was 76° F (24° C) when burning commenced 4:00 p.m. Although the slash burned readily after being ignited with drip torches, several small areas without slash (less than 10 percent of the area treated) did not burn at all. Most huckleberry shoots were blackened, but not consumed by the fire.

Brown and Burn

Firelines were constructed around the four brown-and-burn plots in October 1973. These plots were treated with a low volatile ester of 2,4-D on July 23, 24, 25, and 26, 1974. We mixed three lb (1.36 kg) 2,4-D with 3 gal (11.4 l) of diesel oil and 97 gal (367.2 l) of water, then sprayed the resulting emulsion

on all vegetation. The vegetation was dense, and we used about 190 gal of emulsion per acre (1 777 L/ha). Most of the foliage below 10 ft (3 m) turned brown during the following month.

Burning was attempted at the same time that adjacent cut-and-burn plots were successfully ignited, but here it failed. Dry fireline slash along the plot edges burned, but the other vegetation--even the brown pine needles and herbicide-damaged huckleberry shrubs--would not carry a fire. Thus, the brown-and-burn treatment was browned, but not burned. It became a test of broadcast spraying with low volatile 2,4-D ester.

?, 4-D Frill

A one-to-one mixture of 2,4-D amine and water was applied to individual trees on the 2,4-D frill plots. We used a hatchet to cut frills 1.5 in (3.8 cm) apart around every tree larger than 2 in (5 cm) d.b.h. and squirted the 2,4-D solution into the frills with a plastic squeeze bottle (fig. 15). This operation is sometimes referred to as the "hack-squirt" technique. Frill plots were treated on July 8-11, 1974, when remnants of the heavy winter snow pack remained as drifts and huckleberry shrubs were just beginning to produce leaves. The large number of overstory trees (3,200/acre or 8,000/ha) made this treatment very time consuming. It required about 21 man-hours/acre (52 man-hours/ha).



Figure 15.--2,4-D amine being applied to frills cut in an overstory tree. Note hatchet, squeeze bottle, and snowdrift in background. July 1974.

Phellinus (*Poria*) Inoculation

Phellinus weirii (Murr.) Gilbertson (a native, root-rotting fungus that attacks conifers) spreads slowly, but remains in the soil for long periods after it becomes established. Establishment by inoculation could result in continuous, long-term overstory thinning in the huckleberry fields.

Pathologists Earl E. Nelson[11] and Allen W. Todd[12] inoculated 25 well-spaced trees on each of the four *Phellinus* plots. At each tree, two lateral roots were excavated and scarred by removing a strip of phloem and cambium. *Phellinus weirii* inoculum (alder-block cultures) was then placed in contact with the exposed root xylem, wrapped in plastic, and buried. Tree species and diameter, root size, root direction, and the inoculation point on each root were recorded. Azimuths and distances between inoculated trees on each plot were also recorded, and the inoculated trees were labeled with metal tags.

Control

Four control plots were located and permanently marked in the field. No treatments were applied, and the control plots were undisturbed except for periodic measurements of vegetation and berry production.

DATA COLLECTION AND PROCESSING

Vegetation data were collected in 1975 and 1977 on the five-treatment grid by methods used in the bulldoze-and-burn experiment. Only huckleberry cover was recorded below the four 120-ft (36.6-m) lines established on each of the 20 plots. Overstory cover was recorded by species on the grid plots, however, and both total overstory and overstory cover by species were obtained.

Berry production was measured in 1975 and 1977 by picking and weighing all the berries on 16 systematically spaced 1-milacre (0.0004-ha) subplots on each of the 20 plots. Picked weights were converted to ripe weights by using the procedure described on page 13.

Ripe berry weights, huckleberry cover, and overstory cover were subjected to analyses of variance in 1975 and 1977.

RESULTS

Overstory Vegetation

Overstory vegetation was significantly reduced by the herbicide spray in the brown-and-burn treatment, which affected lodgepole pine more than the other tree species (table 10). The 2,4-D frill treatment was much more effective, however; it killed all but 8.7 percent of the overstory cover (fig. 16). Only the frilled trees were affected by 2,4-D. *Phellinus weirii* inoculations showed no visible results in 1977, and *Phellinus* plot overstories did not differ significantly from the controls (fig. 17).

[11] USDA Forestry Sciences Laboratory. Corvallis, Oregon.

[12] Oregon State University, Corvallis, Oregon.

Table 10—Average berry production, huckleberry cover, and overstory cover on the Mount Hood 5-treatment plot grid[1]

Year and treatment	Berry production	Huckleberry cover	OVERSTORY COVER										
			Lodgepole pine	Noble fir	Douglas-fir	Mountain hemlock	Subalpine fir	Engelmann spruce	Western white pine	Grand fir	Western hemlock	Western redcedar	Total all species
	kg/ha[2]	Percent											
1975:													
2,4-D frill	72.43	46.1	2.0	4.3	1.5	0.7	0	0	0	0	0	0	8.5
Phellinus	173.94	42.9	41.3	4.6	5.3	0.7	2.4	0	0.5	0	0	0	54.8
Control	107.14	44.0	46.0	3.7	1.7	0.8	0	0	0.2	0.5	0.1	0	53.0
Brown and burn	0	5.9	22.4	3.1	4.3	1.5	0	2.1	0.1	0	0.2	0	33.7
Cut and burn	2.70	7.1	0	0	0	0	0	0	0	0	0	0	0
1977:													
2,4-D frill	192.90	49.1	3.1	2.8	1.8	0.9	0	0	0	0	0	0.1	8.7
Phellinus	105.56	45.0	43.9	5.4	5.9	0.9	0.7	0	0.8	0	0.2	0	57.8
Control	73.55	45.2	52.1	4.2	2.5	1.0	0	0	0.3	0.5	0.1	0	60.7
Brown and burn	16.18	28.0	28.3	3.9	5.8	2.0	0	0.6	0.1	0	0.4	0	41.1
Cut and burn	2.36	17.0	0	0	0	0	0	0	0	0	0	0	0

1/ Each average represents 4 treatment plots. Averages within a common bracket are not significantly different (Scheffé tests were not significant at $P<0.05$).

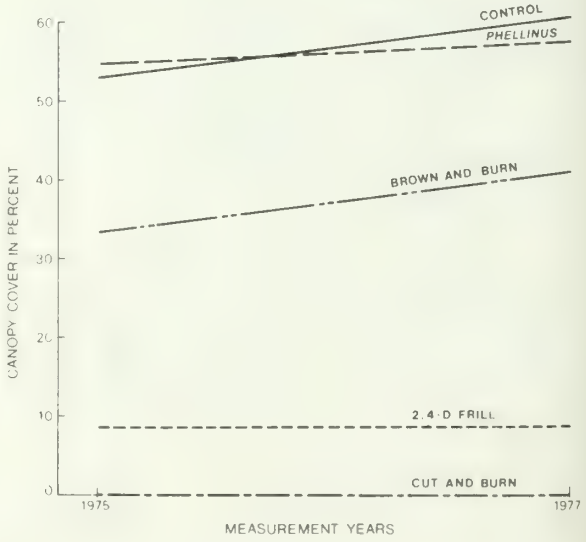
2/ To obtain pounds per acre, multiply by 0.8922.

3/ Absence on most treatment replications made statistical analyses impractical.



Figure 16.--A 2,4-D frill plot 3 years after treatment. Note dead overstory trees. Huckleberry shrubs comprise the understory. September 1977.

Figure 17.--Average overstory canopy on the Mount Hood grid plots. Treatments were applied in 1974.



Overstory species reacted differently to the 2,4-D frill treatment. Lodgepole pine was most susceptible, followed by noble fir, which was more susceptible than Douglas-fir. Mountain hemlock was most resistant. All trees affected by the 2,4-D frill treatment died from the top down, not (as in the karbutilate treatments) from the bottom up.

Huckleberry Cover

Although burned shrubs sprouted vigorously, burning significantly reduced the huckleberry cover measured on cut-and-burn plots in 1975, 1 year after treatment. This reduction was still significant 3 years after treatment, in 1977 (table 10). The brown-and-burn plots were never successfully burned, but they also experienced a significant reduction in huckleberry cover in 1975, a reduction caused by the 2,4-D spray used for browning. Herbicide damage seems to have affected the huckleberry plants less severely than fire damage, however, for by 1977 the average huckleberry cover on brown-and-burn plots, though still much less than that of the controls, appeared to be increasing faster than on the cut-and-burn plots.

Huckleberry cover on the 2,4-D frill, *Phellinus*, and control plots all increased slightly from 1975 to 1977. No significant differences occurred among these three treatments.

Berry Production

As it did in the Mount Adams experiment, the cut-and-burn treatment at Mount Hood essentially eliminated huckleberry production 1 year after treatment (table 10). The few berries picked in 1975 came from shrubs that were not burned. Three years after treatment, in 1977, berries were still limited to those few shrubs, and no increase in production occurred. Burned shrubs sprouted vigorously during the 1st year after treatment, but produced no berries 3 years after burning (fig. 18).

Berry production was also eliminated on the brown-and-burn plots 1 year after treatment. Huckleberries sprayed with 2,4-D bore a few berries again during following years, however, and in 1977 the brown-and-burn plots produced much more than the cut-and-burn plots (table 10). Nevertheless, berry production on brown-and-burn plots was far below the production attained on control, *Phellinus*, or 2,4-D frill plots.

Although berry production on the *Phellinus* plots was higher than that on control plots in both 1975 and 1977, the difference was not statistically significant in either year. Production was appreciably lower for both treatments in 1977 than it was in 1975 (table 10). *Phellinus weirii* inoculations did not affect berry production.



Figure 18.--Huckleberry shrub on a Mount Hood cut-and-burn plot, 3 years after burning. Note vigorous young shoots and absence of berries. September 1977.

Fewer berries were produced on the 2,4-D frill plots than on the control plots in 1975, but the difference was not statistically significant. Three years after treatment, in 1977, the frill plots produced more than twice as many berries as the controls, and the difference was significant. Furthermore, although production declined on all other plots but those recovering from herbicide spraying between 1975 and 1977, it increased during the same period on 2,4-D frill plots (fig. 19). Huckleberries were abundant on the frilled plots in 1977 (fig. 20).

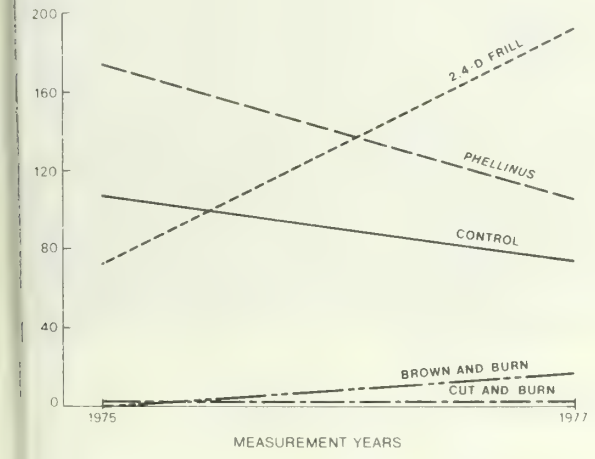


Figure 19.--Average berry production on the Mount Hood grid plots. Treatments were applied in 1974.

CONCLUSIONS

Although the Mount Hood experiment was not contaminated with diesel oil, the cut-and-burn treatment was no more successful there than it was near Mount Adams. Huckleberry shrubs burned in the summer or autumn sprout during the following summer, but do not produce berries for at least 3 years after the fire.

One-year-old slash carries fire satisfactorily, and flame-thrower burning is not necessary if this slash is burned during warm dry weather. Warm dry weather probably will not be sufficient for a satisfactory burn in high elevation huckleberry areas where dry slash is absent, however. Success in burning may require that it be done during high-hazard conditions, which are infrequent. Low fuel densities, frequent fogs, and heavy dews seem to be responsible for unsatisfactory burning. Herbicide browning of the foliage does not provide enough dry fuel to carry a fire on slash-free sites. *Phellinus wierii* inoculations might thin the overstory canopy without the need for either fire or slash, but *Phellinus* has had no visible effect on our plots. We can only conclude that benefits of inoculation, if any, will be slow in appearing.



Figure 20.--Huckleberry shrub on a 2,4-D frill plot, 3 years after treatment. Note abundant berries. September 1977.

Application of 2,4-D amine in frills had little effect on berry production during the first year after treatment, but it greatly reduced the overstory canopy. This reduction in overstory canopy was accomplished without damaging the huckleberry understory. It created favorable conditions for berry production.



LABORATORY RESEARCH

Considerable time and effort were spent in culturing huckleberry in laboratory growthchambers and greenhouses. Our initial attempts were rooting trials. Two thousand stem cuttings were collected from dormant shoots in June 1972. These cuttings were placed in a peat-sand mixture under intermittent mist. All broke buds. None rooted. In late July, another 2,000 stem cuttings were collected from growing shoots. They were soaked in an indolebutyric acid solution (25 mg IBA/1 water) overnight, then rinsed before being placed in the peat-sand mixture under intermittent mist. Again, none of the stem cuttings rooted. Rhizome cuttings grew vigorously, even when collected in midsummer and potted without further treatment.

As our attempts to root stem cuttings failed, and as uniform plants are difficult to obtain from rhizome cuttings, we cultured *Vaccinium* plants from seed. *V. membranaceum, V. globulare,* and *V. deliciosum* all grew equally well under the conditions described.

Ripe berries were pulped in a blender with water and a small amount of detergent added to wet the seeds and prevent them from floating away with the pulp. The resulting slurry was placed in a dish and decanted under a slow stream of water. The pulp floated away, leaving the seeds in the dish bottom. These seeds were air-dried, then sown on moist peat kept at cool growthchamber temperatures (18° C or 64° F, 12-h days and 13° C or 55° F, 12-h nights were satisfactory). Seed stratification was not necessary, and germination occurred in 16-21 days.

The resulting seedlings grew rapidly when watered periodically with a nutrient solution based on the macronutrient proportions published by Ingestad (1973) and the micronutrients listed by Minton, Hagler, and Brightwell (1951):

Macronutrient Solution (in 1 liter H_2O)

0.048 g $NH_4H_2PO_4$

0.095 g KCl

0.041 g $Ca(NO_3)_2 \cdot 4H_2O$

0.086 g $MgSO_4 \cdot 7H_2O$

0.341 g NH_4Cl

Micronutrient Stock Solutions[13]

0.90 g manganese chloride/500 ml H_2O

0.10 g zinc sulfate/500 ml H_2O

0.05 g cupric sulfate/500 ml H_2O

0.50 g boric acid/500 ml H_2O

0.08 g molybdic acid/500 ml H_2O

19.23 g sequestrine NaFe/500 ml H_2O

[13]One ml of each stock solution was added to each liter of macronutrient solution.

Excellent growth occurred in chambers set for 20° C (68° F), 14-h days and 14° C (57° F), 10-h nights. When well watered, the plants also grew satisfactorily in greenhouse and lathhouse conditions.

When *V. membranaceum* plants were grown from seed, they first bloomed during their third growing season. Rhizomes were first formed during the third growing season (fig. 21). Rhizome formation in *V. deliciosum* apparently occurs much earlier--we found rhizomes on 1-year-old growthchamber seedlings.

Using *V. membranaceum* cultured from seed, we cooperated with an Oregon State University graduate student who studied the relation of nutrients and pH in a greenhouse and in the field (Nelson 1974). He found in both places that vegetative growth increased with added nitrogren. Better growth in the greenhouse occurred at pH 5.0 than at 3.0, 4.0, or 6.0. *V. membranaceum* seedlings were also used in a study of the comparative tolerances of huckleberry and lodgepole pine to boron and manganese (Minore 1975a).



Figure 21.--V. membranaceum *rhizome produced during the third growing season in a lathhouse. Our growth chamber, greenhouse, and lathhouse plants formed no rhizomes during their first two growing seasons.*

The pine was more tolerant to boron. We used seedlings of *V. membranaceum, V. deliciosum,* and *V. globulare* in a carefully controlled study of frost tolerance (Minore and Smart 1978). *V. deliciosum* was significantly more frost tolerant than the other species.

Beargrass is a major competitor in the huckleberry fields and in high elevation clearcuttings, but herbicides, burning, and grazing have been ineffective in controlling it. Past attempts to culture beargrass have been hampered by the inability to germinate the seeds. After trying several methods, we obtained successful (64 percent) germination by stratifying the seeds for 16 weeks (Smart and Minore 1977). The seedlings were successfully cultured under the same nutrient, temperature, and photoperiod regimes used in growing *V. membranaceum.*



DISCUSSION

Although we tested vegetation control methods in only two areas, these areas appear to be typical of the berryfields that occur at elevations of 4,000-6,000 ft (1 220-1 830 m) in the Cascade Range of Oregon and Washington. Lodgepole pine, western white pine, beargrass, lupines, and grasses are the most important huckleberry competitors in the areas studied. Burning the slash created by cutting or pushing over all trees with a tractor eliminated the lodgepole and white pine competition. Beargrass, lupines, and grasses, however, were not satisfactorily controlled. Indeed, grass growth was stimulated by burning.

Controlled burning is exceedingly difficult in northwestern huckleberry areas at these elevations. Without dry slash to carry the fire, burning appears impossible except during hazardous meteorological conditions; it seems counterproductive when short-term benefits are desired. Abundant berries did not occur after our fires. Although the huckleberry bushes sprouted almost immediately after being burned, the sprouts did not begin to bloom until the third growing season. Significant berry production was delayed for at least 5 years and perhaps much longer. Meanwhile, tree seedlings from adjacent unburned stands began to invade the burned area. Unless this area is very large (comparable to the areas burned by wildfires in former years), reinvasion of burned areas by trees may be almost as fast as huckleberry recovery.

Spring burning increased *V. globulare* stem density within 1 year in the larch/Douglas-fir forests of western Montana (Miller 1977), but Montana results may not apply to huckleberry in Oregon and Washington. Western Montana environments differ from Pacific Northwest environments. Furthermore, the morphology and sprouting behavior of *V. globulare* in Montana resemble that documented for *V. angustifolium* (Miller 1978); behavior of big huckleberry does not resemble that of *V. angustifolium*, so it probably also differs from that of *V. globulare*. *V. globulare*, like *V. angustifolium*, may recover from fire more rapidly than big huckleberry.

Season of burning--not species differences--probably was responsible for higher stem density on some of the Montana fire plots. Density-increasing burns there occurred in the spring, when soil moisture was higher and heat penetration was shallower than in the autumn. The Montana autumn burns, like our burning treatments, reduced stem densities. As our Mount Adams burning treatments were applied less than 2 weeks after an early autumn snowfall, however, and as the Mount Hood burning was done only 5 weeks after the disappearance of a heavy winter snow pack, our burns may have occurred under soil moisture conditions similar to those of a Montana spring. In any case, snow cover makes spring burning impossible in most northwestern huckleberry fields. Summer and autumn burning reduced both stem density and berry production for at least 5 years.

Sheep grazing--even severe overgrazing--did not damage the huckleberries. It may even have benefited them by adding nitrogen to the soil. Unfortunately, added nitrogen is of little value to huckleberries growing under a closed forest canopy, and sheep grazing does not eliminate this forest canopy or retard its closure.

Applications of karbutilate eliminated the forest canopy, but they also eliminated the huckleberries growing under that canopy. The huckleberries could recover and sprout again, but the prospects are not encouraging. Boron applications are even less encouraging and should not be considered further.

Successful *Phellinus weirii* inoculations probably would maintain an open overstory indefinitely. As yet, the inoculations have not been successful, however, and we will have to wait several more years to see if this form of biological control merits further investigation.

Application of 2,4-D amine to frills cut in each treated tree certainly deserves further investigation. The method is expensive in dense stands like those treated near Mount Hood, but it would be an economical way to eliminate trees at earlier seral stages when stand

density is much lower. We found no evidence of the 2,4-D moving out of treated trees. Applied in frills, the herbicide appeared to be safe as well as efficient.

Dense shade is detrimental to huckleberry production, and some sort of overstory control is needed to preserve and maintain existing berry fields. Partial shade does not seem to be harmful, however, and the slight overstory protection afforded by dead snags or a thin overstory canopy may even be beneficial. Absolutely open conditions, without shade of any kind, may be less desirable than this light partial shade.

Shrub disturbance is detrimental to production of huckleberries. Old shrubs continue to produce berries year after year, without pruning or other rehabilitation. When these old shrubs are burned, cut, or otherwise disturbed, they stop producing berries and start producing vigorous new shoots. Unfortunately, vigorous new shoots do not produce many berries.

Vigorous new shoots should produce many berries eventually, however. When they do, areas that were disturbed by burning may be more productive than undisturbed areas. The long-term benefits of burning might then exceed the short-term benefits obtained by applying 2,4-D in frills. We will continue to monitor all of our experimental plots to see if this occurs.



MANAGEMENT RECOMMENDATIONS

Huckleberry management will be expensive, and the areas to be managed should be carefully selected. Access, public use, and berry production should all be considered. In many areas, the public already is using easily accessible areas that are known to produce good berry crops. Preserving and maintaining these traditional picking grounds should be given highest priority. The following recommendations are applicable to huckleberry areas at 4,000-6,000 ft (1 220-1 830 m) in the Cascade Range of Oregon and Washington.

Overstory trees should be controlled in the areas to be managed. If berry production is to be maintained or increased without delays of 5 years or longer, this must be done with minimal disturbance of the huckleberry understory.

A one-to-one solution of 2,4-D amine and water, applied to frills cut in the individual trees, effectively kills a conifer overstory without disturbing the huckleberries. It should be applied in the spring, just as conifer buds are breaking. Where herbicide use is undesirable, individual tree girdling would produce the same result at somewhat higher cost. Frilling and girdling will be least expensive when done before a dense overstory canopy develops.

Where dense overstory canopies occupy large areas that are to be managed for huckleberries, and where berry production delays of 5 years or longer are acceptable, the bulldoze-and-burn treatment should be considered. Using a crawler-type tractor with raised bulldozer blade, all trees in a large area should be pushed over and allowed to dry for a year before burning is attempted. Burning should then be done while soil moisture remains high, as soon as the slash will carry a fire. This method has a severe visual impact on the landscape, it will eliminate berry production for several years, and long-term berry production benefits are unknown. Nevertheless, it is much cheaper than frilling or girdling where dense unmerchantable overstories are to be removed. Where merchantable overstories exist, conventional clearcutting probably would be just as effective. Unfortunately, merchantable overstories do not always occur on areas capable of producing good huckleberry crops.

Sheep grazing is compatible with huckleberry production, but sometimes incompatible with huckleberry pickers. Wherever possible, grazing should be scheduled so that sheep are out of the berry fields before the huckleberries ripen.

Where optimal growth and berry production are desired, nitrogen fertilization is beneficial. Nelson's work (1974) indicated that 40 lb of nitrogen per acre (44.8 kg/ha) produced a response nearly equal to the maximum possible response from field fertilization. To supply this amount of nitrogen, he used 191 lb of ammonium sulfate/acre (214 kg/ha).

If intensive huckleberry management is ever attempted, the young shrubs probably should be planted in heavily used berry fields or recent clearcuttings in berry-producing areas. Cultural techniques are available, and these shrubs can be produced from seed with little difficulty. In high elevation areas where spring frosts cause frequent crop failures, the frost-resistant blueleaf huckleberry could be introduced and managed. It is low-growing and difficult to pick, however, and seems to be less productive than big huckleberry. Mixtures of these two species probably should be grown where frequent frosts occur in the growing season.



LITERATURE CITED

Black, W. 1963. The effect of frequency of rotational burning on blueberry (*Vaccinium angustifolium*) production. Can. J. Plant Sci. 43(2):161-165.

Canfield, R. H. 1941. Application of the line interception method in sampling range vegetation. J. For. 39:388-394.

Fernald, Merritt Lyndon. 1950. Gray's manual of botany. 8th ed. 1,632 p. American Book Co.: New York, Cincinnati, Chicago, Boston, Atlanta, Dallas, San Francisco.

Garrison, G. A., J. M. Skovlin, C. E. Poulton, and A. H. Winward. 1976. Northwest plant names and symbols for ecosystem inventory and analysis. USDA For. Serv. Gen. Tech. Rep. PNW-46, 263 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Hitchcock, C. Leo, and Arthur Cronquist. 1973. Flora of the Pacific Northwest. 730 p. Univ. Wash. Press, Seattle.

Ingestad, Torsten. 1973. Mineral nutrient requirements of *Vaccinium vitis idaea* and *V. myrtillus*. Physiol. Plant. 29(2):239-246.

Miller, Melanie. 1977. Response of blue huckleberry to prescribed fires in western Montana larch-fir forest. USDA For. Serv. Res. Pap. INT-188, 33 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Miller, Melanie. 1978. Effect of growing season on sprouting of blue huckleberry. USDA For. Serv. Res. Note INT-240, 8 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Minore, Don. 1972. The wild huckleberries of Oregon and Washington--a dwindling resource. USDA For. Serv. Res. Pap. PNW-143, 20 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Minore, Don. 1975a. Comparative tolerances of lodgepole pine and thin-leaved huckleberry to boron and manganese. USDA For. Serv. Res. Note PNW-253, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Minore, Don. 1975b. Observations on the rhizomes and roots of *Vaccinium membranaceum*. USDA For. Serv. Res. Note PNW-261, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Minore, Don, and Michael E. Dubrasich. 1978. Big huckleberry abundance as related to environment and associated vegetation near Mount Adams, Washington. USDA For. Serv. Res. Note PNW-322, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Minore, Don, and Alan W. Smart. 1975. Sweetness of huckleberries near Mount Adams, Washington. USDA For. Serv. Res. Note PNW-248, 4 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Minore, Don, and Alan W. Smart. 1978. Frost tolerance in seedlings of *Vaccinium membranaceum, Vaccinium globulare,* and *Vaccinium deliciosum.* Northwest Sci. 52(3):179-185.

Minton, Norman A., T. B. Hagler, and W. T. Brightwell. 1951. Nutrient-element deficiency symptoms of the rabbit eye blueberry. Proc. Am. Soc. Hort. Sci. 58:115-119.

Nelson, Eric A. 1974. Greenhouse and field fertilization of thin-leaved huckleberry. USDA Forest Serv. Res. Note PNW-236, 13 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Peck, Morton Eaton. 1961. A manual of the higher plants of Oregon. 2d ed. 936 p. Binfords and Mort, Portland.

Scheffé, H. 1959. The analysis of variance. 477 p. Wiley, New York.

Smart, Alan W., and Don Minore. 1977. Germination of beargrass (*Xerophyllum tenax* (Pursh) Nutt.). Plant Propagator 23(3):13-15.

Smith, D. W., and J. R. Hilton. 1971. The comparative effects of pruning by burning or clipping on lowbush blueberries in north-eastern Ontario. J. Appl. Ecol. 8(3):781-789.

Smith, W. W., A. R. Hodgdon, and Russell Eggert. 1947. Progress report on chemical weed control in blueberry fields. Proc. Am. Soc. Hort. Sci. 50:233-238.

Noble fir2/3/	Violet	Alpine willow-herb3/	Grand fir2/3/	Total huckleberry competition
0	0	0	0	58.8
0	0	0	0	63.2
0.1	0	0	0	56.6
0	0	0	0	65.6
--	--	--	--	--
0	0	0	0.1	53.5
0	0	0	0.1	56.6
0.2	0	0	0	50.7
0	0.1	0	0	38.9
0	0.1	0	0	36.5
0	0	0	0	47.2
0	0	0	0	50.1
0.2	0.1	0.1	0	46.3
0	0	0.1	0	40.7
0	0	0.1	0	42.9
0	0	0.1	0.2	44.1
0	0	0.1	0	45.2
0.2	0.1	0.1	0.2	40.9
0	0	0.1	0	33.1
0	0	0	0	23.3
0.1	0.1	0	0	57.2
0	0	0	0	58.9
0.2	0.2	0	0	56.9
0	0	0	0	59.4
0	0.1	0	0	54.5

ıental area[1]

WS2/	Western white pine2/	Western wood strawberry	Pearly ever-lasting	Sec
	4.9	1.6	1.3	1
	5.4	1.2	2.4	1
	4.1	1.4	1.3	0
	2.7	1.3	2.9	1
	--	--	--	
3	4.1	1.6	1.2	0
)	4.6	1.8	0.7	1
-	3.7	2.6	0.9	1
2	0.1	1.6	2.0	1
	0	1.6	2.1	2
6	3.0	2.7	1.4	0
8	4.2	2.7	1.0	1
3	3.5	4.4	1.5	1
6	0	2.5	3.7	2
	0	2.8	3.7	3
1	3.8	2.3	0.8	1
9	5.0	2.0	0.5	2
4	4.1	3.4	1.1	1
6	0.1	2.0	2.2	
	0	1.3	1.5	2
.5	3.4	2.5	1.1	0
.3	4.5	2.6	1.1	0
.4	2.8	3.2	2.2	2
.7	0.1	3.1	3.7	
.1	0	3.6	4.0	3

ithin a common bracket are not signific

1-m height of our intercept tape.

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treatment plots in 1972.

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key--out of the reach of children and animals--and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly. Spills of herbicides or spray adjuvants should immediately be cleaned from work surfaces and mixing platforms. Spray adjuvants such as Vistik, Dacagin, Norbak, and foaming agents are especially slippery and should be immediately flushed off with water.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.



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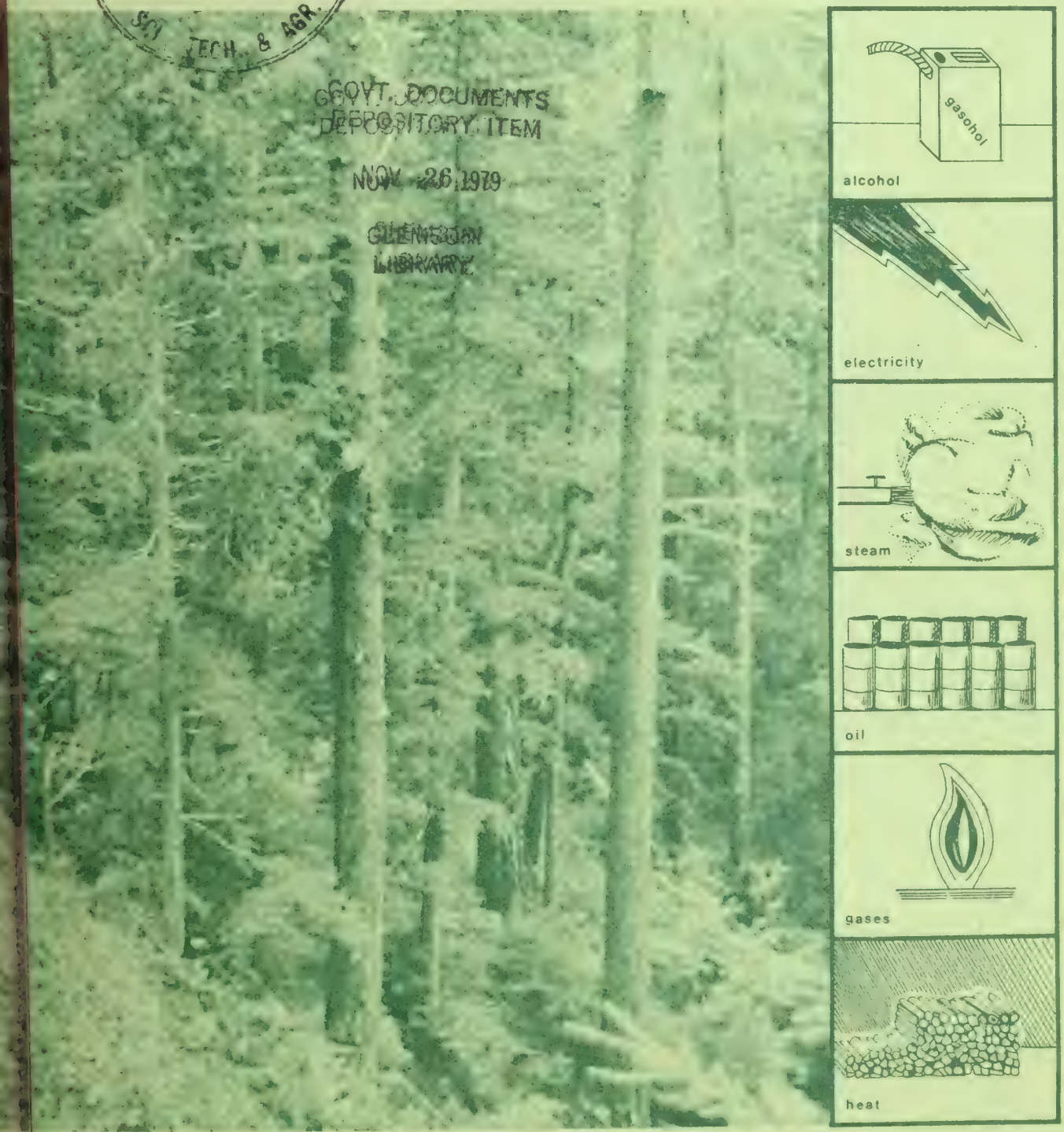
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Wood for Energy in the Pacific Northwest: An Overview

James O. Howard



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ABSTRACT

This report presents an overview of the technology of converting wood to energy and the availability of wood.

The first section describes fuel values and significant processes used to generate various energy products from wood. Physical, technical, and economic availability of the wood resource is discussed in the second section. The paper concludes with an outline of some critical problems in handling wood and some socioeconomic factors that impact the production of energy from wood.

An extensive bibliography covers topics discussed in the paper.

KEYWORDS: Energy, biomass, wood utilization, Pacific Northwest.

Introduction

Recent shortages of energy and rapidly escalating prices for natural gas and petroleum products have generated much interest in development of alternative sources of fuel. Wood, one of our most abundant renewable resources, has been the focal point for a great deal of this activity.1/

The objectives of this report are to present a summary of the state of the art of the technology of converting wood to energy and to discuss the wood resource base from which energy might be produced.2/ The information is aimed at a wide audience at planning and management levels in both the private and public sector of the United States.

This report focuses on wood biomass, either from standing trees or the material left after harvesting and manufacturing operations. Other forms of biomass, such as agricultural and municipal wastes, will only be considered as they interface with wood in situations favoring use of multiple feedstocks for production of energy.

Most of the data were drawn from sources for the State of Oregon. Less emphasis on the other Pacific Coast States does not imply that similar opportunities do not exist. In almost all cases, conclusions inferred from the Oregon data apply directly to Washington and California. The conclusions, however, may not apply to Alaska because of the special physical and socioeconomic circumstances prevailing in that State.

Wood as a Fuel

Wood has long been used as a fuel for producing energy. The history of wood use for energy is well documented and need not be presented here. The issue is not one of new products, although there are a few, but rather one of advancing the technology of using wood for energy and of insuring adequate supplies for large-scale applications. In addition, the possibility of removing the total biomass from a given area has raised questions about future productivity of sites and stability of soil and water.

The forest products industry is the largest user of wood for energy in the Pacific Northwest. In 1976, about 4.3 million tons (dry weight) of mill residues were used for fuel, mostly by the industry itself (*33*). The primary use was to fuel boilers for steam or direct heat, and, in a few cases, for electricity (*21, 37*). Although not produced in large quantities locally, charcoal and various chemicals are also produced from wood. The forests of this region supply a great deal of fuelwood for residential consumption. Use of fuelwood has increased

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1/ "Wood," as used in this report, includes bark, unless otherwise specfied.

2/ "Energy" refers to a wide range of products, including electricity, steam, gases, oil, alcohols, and various chemicals.

considerably the past few years. Although data on consumption of fuelwood from all lands are not available, the USDA Forest Service reported that about 378,000 dry tons were removed from Oregon and Washington National Forests in fiscal year 1978. The trend in residential use would appear to be upward in light of recent increases in sales of wood stoves for heating homes.

The energy value of wood is usually measured in terms of its heat value, expressed as British thermal units (Btu) per ovendry pound. Resin has a higher heat value than wood, about 17,000 Btu per pound (*11*). Thus, resinous softwoods have a higher heat value than hardwoods on a weight basis; however, hardwoods produce more Btu's on a volume basis because of their greater density. Energy values in this report are expressed on an *ovendry* basis.

Actual heat values of wood do not vary significantly between species. Since moisture content has a greater impact on available heat than species, average values are used in most analyses. Various studies indicate the heat value of most softwoods to be between 8,300 and 9,000 Btu per pound (*4, 11, 34, 50*). The wood of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is estimated at 8,600 to 9,200 Btu per pound; the bark at 9,400 to 10,100. Bark values are generally higher because of greater concentrations of resin, less cellulose, and a higher proportion of lignin. Heat values for hardwoods range from 8,000 to 8,800 Btu. Red alder (*Alnus rubra* Bong.) is estimated at 8,000 Btu.

Little information is available on which to base estimates of heat values resulting from utilization of the whole tree. A higher proportion of bark in the upper stem portion would generally lead to higher heat values. In addition, the resinous nature of softwood needles would raise the heat values somewhat.

Material commonly used for fuel in the forest products industry is generally referred to as hogged fuel or "hog fuel." This fuel usually has a high proportion of bark with an average heat value of 8,500 to 9,000 Btu per pound. Although hog fuel from hardwoods is not marketed extensively in the Pacific Northwest, heat values should range from 8,000 to 8,500 Btu per pound.

Wood is a clean burning fuel and offers some advantages over conventional fuels, such as coal. The ash content of wood is very low, less than 3 percent by weight. Bark has a slightly higher level. The ash content of coal on the other hand is 3 to 5 times higher. Thus, disposal problems are fewer when wood is used as a fuel. Sulfurous compounds are a special problem encountered when coal or oil is burned. Wood, however, has a negligible sulfur content, making it easier to meet air pollution standards. A crucial problem in using wood as a fuel is meeting standards for smoke and particulate matter, which may require expensive equipment to comply with standards for visible emissions. Advances in the technology of combustion, such as fluidized bed burners, should aid in decreasing costs of meeting environmental standards in the future.

In certain situations, wood may be used in conjunction with other fuels to produce energy. The use of two or more feedstocks for energy production is referred to as cofiring. Cofiring may involve conventional fuels, such as coal and oil, or municipal and agricultural wastes in conjunction with wood. In general, the various feedstocks are not processed simultaneously, although this may be possible with certain technologies.

A new coal-fired electric facility, owned by Portland General Electric Company (PGE), is being constructed to accept wood for as much as 20 percent of its fuel, although such use is not now planned on a production basis. A Georgia Pacific pulpmill in Toledo, Oregon, uses hammer-milled tires as a partial source of fuel to produce steam. Wood and municipal waste are being considered as fuel sources for some pyrolytic processes elsewhere in this country.

A major advantage of cofiring is the use of a resource that does not exist in sufficient quantities to fully fuel an energy facility. This will be the case in many areas where municipal or agricultural wastes are being considered as fuels. Using wood waste as a backup source of fuel has been given consideration in studies of grass straw utilization. The wood can be used as fuel when seasonally produced fuels or supplies of other fuels are not available.

Certain problems are encountered when more than one feedstock is used for energy. Preparation and handling requirements of different fuels may necessitate additional equipment and thereby increase capital costs. Generally, materials have to be prepared so that physical properties are similar. Equipment for controlling pollution may have to be more flexible, again increasing costs. Finally, operation costs may be higher because of the need for increased monitoring of controls as feedstocks change.

Conversion Technologies

Energy in various forms can be produced by combustion or by thermochemical or aqueous processing of wood. Figure 1 shows the common products that can be produced by each of these processes. The following discussion will describe each process and the resulting products.

Direct Combustion

Direct combustion of wood is the oldest form of energy known, other than sunlight. In its simplest form, radiant heat is utilized from open burning in an enclosure, such as a fireplace or pit. Commonly used in homes, this process is inefficient; its main appeal is esthetic. Use of airtight wood stoves increases overall efficiency of burning fuel and thus offers some incentive to residents where fuelwood costs are reasonable. Although not very efficient overall, home heating does produce energy from wood that would not be utilized otherwise.

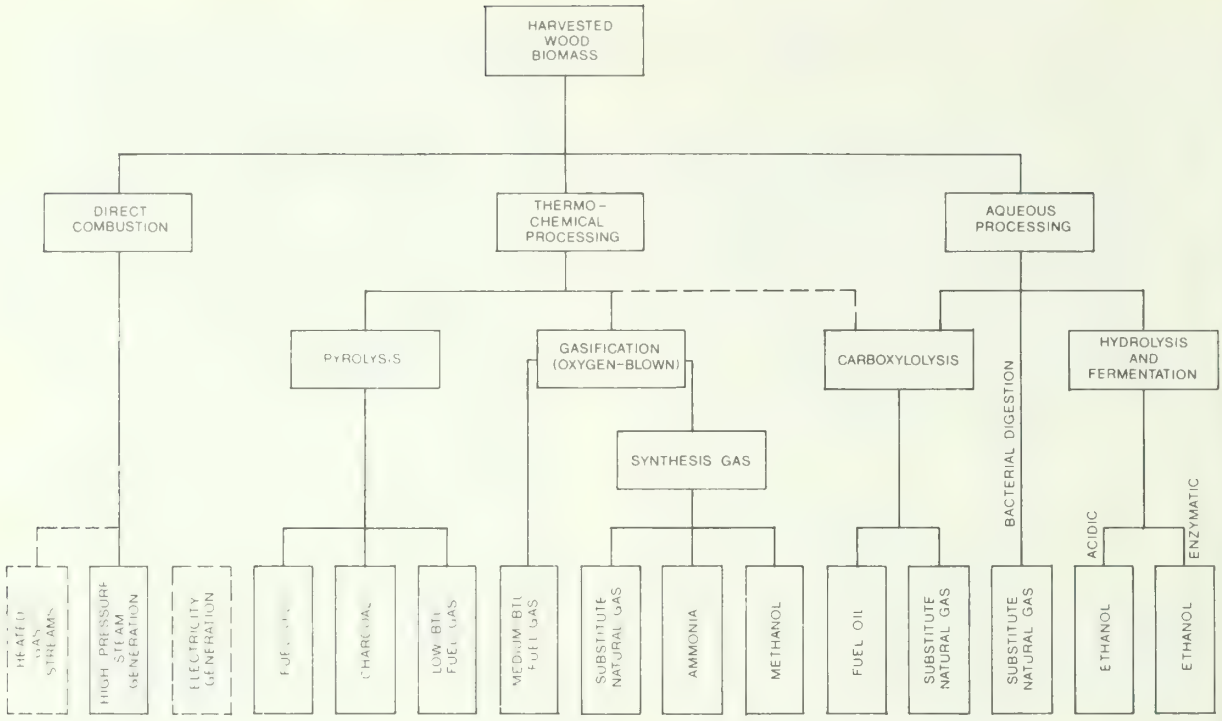


Figure 1.--Alternative conversion routes for producing energy-related products from wood (Source: Mitre Corp., Silvicultural Biomass Farms (50)).

Wood has been used as a fuel by industry for some time (2). Interest in hog fuel has increased considerably in recent years after a continuous decline from levels of the late 1800's. Regionally, the forest products industry is the major user of hog fuel. Many mills utilize boilers to produce steam for operating equipment, drying products, and, in some cases, generating electricity. The largest non-forest industry user of wood for energy in Oregon is Eugene Water and Electric Board. This local utility consumes about 240,000 tons annually, producing both electricity and steam for local businesses (7).

Several combustion systems are available which can utilize hog fuel. The most common burners in use are the fixed- and moving-bed variety. Prior to 1940, most burners were two-stage furnaces referred to as "Dutch ovens"; in these systems, fuel is fed into a firebox where moisture evaporates and partial gasification occurs. The hot gases are then vented into the boiler where combustion is completed and steam produced. A more recent version of the Dutch oven, the fuel cell burner, is highly automated and uses a water-cooled grate. This unit is commonly used to heat kilns at sawmills.

Newer burners utilize inclined, pinhole, or moving grates. For the most part, these burners do not require gas or oil for overfiring, as do many older types. Fuel is introduced into the furnace via mechanical or pneumatic stokers, and combustion occurs in suspension and on the grates. Moving or dump grates have the added advantage of making removal of ash easier.

For suspension burners, often used for combustion of coal, the fuel must be reduced to fine particles. In this type of burner, the fuel burns in a large fireball above the grate. Burners of this type using wood have been employed to overfire existing boilers. A disadvantage of this type of burner is the added effort and cost required to reduce wood to the necessary size. An exception is sander dust which burns well in suspension.

A newer type of suspension burner is the cyclonic variety (*19*). This system uses forced air to hold fuel in suspension until combustion is complete. These burners are small modular units with broad application for drying chips or solid wood products and generating steam (*10, 13, 36*). In one case, installation of wood-fired cyclone burners for drying veneer resulted in annual savings in fuel costs of $450,000 (*21, 69*). It should be noted that these savings were based on mill residues having zero value, which is not the case for most mills.

Much interest has recently been generated concerning the combustion of wood in fluidized-bed burners. This concept involves passing a gas stream, such as air, upwardly through a bed of inert particles (*5, 19, 41, 44, 52, 54*). This agitated, fluidlike bed results in high heat and high mass transfer rates. Lower bed temperatures reduce sintering and agglomeration of ash and thus facilitate removal. A special advantage of this type of burner is the ability to burn fuels of various sizes and moisture contents. One such burner being tested in Washington operates on a mixture of millyard waste, wet sawdust, old chips, and sawmill end trim. A burner such as this can play an important part in overall management of mill residues and waste. Another advantage of the fluidized bed is the ease of handling noncombustibles, such as metal or rocks. Results from early tests also indicate very low levels of particulate emissions (*44*).

As will be discussed later, fluidized-bed reactors are being tested for the gasification of wood. This system, using coal or municipal wastes, has been used extensively in Europe for many years (*31, 47*).

The preceding discussion focused mainly on the production of steam or process heat for industrial use. Generation of electricity--an alternative that has captured much interest lately (*17, 18, 26*)--at a central power facility appears to be economically questionable at this time. Several factors act as impediments to generation of central power. Economies of scale favor large thermal powerplants. Current technology, however, limits the size of wood-fired boilers so that generation of electricity in excess of 100-150 megawatts (MW) is not practical. Most existing or planned wood-based facilities are 50 MW or less. A second problem associated with size is that of fuel supply. For example, a 100 MW plant operating at 75-percent capacity would consume about 600,000 dry tons annually. A long-term supply of

this quantity of wood cannot be assured (*46*). In addition, there are special problems in handling and storing this mass of material.

Several studies have shown the price of wood-fueled power to be competitive with new conventionally fueled plants (*7, 38, 50*). Although the data base for these conclusions is not especially strong, a more pressing concern is the existing pricing structure for electricity. Many people consider the low-cost electric power in the Northwest to be a major deterrent to small scale, nonutility generation of electricity from wood. In general, most consumers of industrial power consider it cheaper and less troublesome to continue purchasing electric power than to install equipment to generate their own power.

The general environment surrounding power generation is constantly changing and varies throughout the country (*24, 30*). More costly power and less certainty about future supplies spurred the city of Burlington, Vermont, to pass a bond issue for a 50-MW wood-fired powerplant (*30*).

A concept currently receiving much attention is cogeneration. This is defined as the concurrent production of process steam and electricity from a boiler system. This has most frequently been done at pulpmills utilizing kraft black liquor as the fuel source. Faced with rising prices for power and the potential for interrupted supplies, the forest product industry has been giving this concept much attention lately.

There are many options for equipment to produce steam and electricity, depending on a mill's needs. The choice of turbines ranges from fully condensing turbines to extractive turbines which allow removal of steam at various pressures. Back pressure turbines, of which extractives are a variety, vent steam at relatively low pressures for industrial use. The proper choice of equipment depends on steam requirements and quantity of electricity needed. In some situations a plant may sell both steam and electricity to outside users and thus enhance the economics of the operation.

A major deterrent to extensive application of cogeneration is the existing marketing structure for electricity. It is difficult to find outlets for privately generated electricity. Local utilities will frequently pay only a portion of the cost of the power. Thus, nonutility producers must look elsewhere for purchasers. By working with Bonneville Power Administration (BPA), U.S. Department of the Interior, through its power management position, customers outside the region may be found. If a contract is secured, power can be wheeled throughout a complex trading system.

A major breakthrough in power generation could occur if BPA was able to purchase power under a roll-in pricing scheme. Under this framework, higher cost new power is averaged in with existing cheaper power. The result would be slightly higher prices and larger supplies for all users. Given the authority, BPA might also trade power with the small producer. A

possible drawback is that BPA might need power at the same time as the producer.

Aside from the problems mentioned above, cogeneration is the most likely candidate for short-term increases in power supplies (*16*). Even with no changes in the marketing structure, the threat of a power cutoff might result in installation of steam-driven turbines (*56*). Some larger mills in the region currently sell or trade electricity, and a number of mills are closely scrutinizing this option.

Pyrolytic Conversion

Pyrolytic conversion of wood into energy-related products is not a new process. Charcoal has long been made by this process. What is new is the diversity of products being considered and the advancing technology on use of reactors. Although fairly common in Europe, the use of pyrolytic techniques to produce gases and oil is just emerging in this country. Most applications to date have used coal or municipal waste as feedstock (*31*).

A dichotomy in terminology exists in describing this process. When the feedstock is heated to temperatures below 600°C, the process is usually referred to as *pyrolysis*. Products at this level of thermal degradation are gases, oils, and a considerable amount of char. At temperatures above 600°C the process is called *gasification*, resulting primarily in vaporous products with much less carbonaceous residue (*6, 14, 28, 67*). Both pyrolysis and gasification involve thermal degradation of organic matter in an oxygen deficient atmosphere.

The gas produced by this process is referred to as low Btu gas. The gas has a heat value of 150-300 Btu per cubic foot and is composed of hydrogen, carbon monoxide, methane with smaller amounts of nitrogen, and carbon dioxide (*6, 19, 28, 44*). Because it is laden with tars and oils and has a low Btu value (natural gas is about 1,000 Btu per cubic foot) low Btu gas must be consumed close to the production point. Low Btu gas can be converted to pipeline gas or substitute natural gas by a process called methanation. The result is greater transportability, but at a higher cost.

Currently, no significant market exists for low Btu gas. This situation could change radically, however, if legislation restricting consumption of industrial natural gas was enacted. In this event, segments of industry might start producing their own gas rather than converting to other energy sources, such as electricity.

Another product of gasification receiving attention recently is methanol (*22*). Methanol is produced by further refining low Btu gas by catalytic conversion of methane. Methane is currently made from natural gas and has a wide variety of uses, the most significant being conversion to formaldehyde (*40*).

The interest in methanol focuses on its use as a fuel for internal combustion engines. As an additive to gasoline (usually 10-20 percent), forming a product called gasohol, methanol increases power and burns cleaner. Disadvantages of its use are fewer miles per gallon, vaporization, phase separation due

to water contamination, and effects of corrosion on existing fuel systems (*1*). There are indications that use of pure methanol rather than blends would better utilize its unique properties (*1*). For existing cars this would require modification of the fuel-feeding system and an increase in the capacity of the tank.

The greatest drawback to the use of methanol or ethanol as a fuel for cars is cost. Most studies indicate that methanol from wood will currently cost from two to three times as much as gasoline at the plant gate (*1, 51, 63*). Cost aside, recent legislative activites indicate that the use of methanol as a gasoline additive may be decided by public policy at the national level.

One further concern in the production of methanol is the net balance of energy. As much as 62 percent of the energy value of the feedstock is required in the production phase (*38*).

Other products, such as ammonia and furfural, can be derived from pyrolytic processes. Conventional sources are now readily available and cheaper to use. Thus, unless taken as a credit during multiproduct processing, large-scale generation of these products is unlikely within the existing economic environment.

Another product of pyrolytic conversion of wood is substitute fuel oil. These oils can also be produced by a process known as carboxylolysis. This term describes a process by which wood fiber is catalytically converted to oil in the presence of carbon monoxide and water at temperatures of 250°-400°C and pressures of 2,000-4,000 psi (*47, 50*). A pilot plant utilizing this technology is operating in Albany, Oregon. Oil from pyrolysis or carboxylolysis is similar to Number 6 residual oil now being used by industries and for generation of electricity. The wood-based oil is more viscous than Number 6 oil, has a lower sulfur content, and is somewhat more corrosive. Blending of Number 6 oil with the wood-based oil has been considered to take advantage of the better qualities of each (47). Currently, the economics of wood-based oils are not favorable; however, rising petroleum prices and a generally increasing demand for fuel oils indicates potential for the future.

Hydrolysis and Fermentation

This process utilizes hydrolytic agents, such as sulfuric or hydrochloric acids or enzymes, to depolymerize cellulose into sugars. Ethanol can then be produced by fermentation of the sugar. Some interest in sugars is generated where conventional sources are not available. Such is the case in the Soviet Union (50). In this country, the interest is in ethanol for industrial feedstock or as a gasoline additive. A pilot study now underway in Nebraska is testing the use of a 10-percent mixture of ethanol; this "gasohol" sells for about 6 cents per gallon more than pure gasoline. Studies to date indicate that ethanol produced by this process is not competitive in cost and has a very low net energy balance (*1, 40, 50*).

Bacterial Digestion

Production of a gas containing methane and carbon dioxide by bacterial digestion of wood has received some attention. The process is aerobic (oxygen using) or anaerobic (oxygen deficient) and uses the digestive capabilities of various microorganisms (*50*). The process is slow and requires constant monitoring of temperature. There is some indication that the lignin in wood may be toxic to the bacteria.

Bacterial digestion is not now considered a significant fact or in producing energy from wood; animal and municipal wastes are more favored sources.

The Resource Base

The intent of this section is to describe the characteristics and availability of various sources of wood that may be used for energy. Quantities of wood from the various sources will be discussed where data permit. The general thrust is to bring into focus the physical and economic factors affecting the availability of the resource for production of energy. Analyses of case studies of the availability of wood for a specific energy facility are site specific and thus beyond the scope of this report. The discussion that follows points out the potentials and shortcomings of existing resource data as they pertain to energy. The availability of wood for fuel is to a great degree a function of the dynamic economic environment and competition from conventional products.

Mill Residues

Mill residues are generally viewed as a first-line source of wood feedstock for energy and are used as such by the forest products industry. The advantages offered by mill residues are apparent. They are in a convenient form, are readily accessible, are generated in fairly large quantities, and are the cheapest form of wood fiber. The total quantities generated tend to be misleading. In 1976 about 15.4 million tons, dry weight, of wood and bark residues were created by the forest products industry in Oregon (*33*). Of this total, however, only 510,000 tons were reported as unused. This lesser volume represents the most likely source for new products, such as energy. As is indicated by figure 2, no significant concentration of unused residues exists in the State.[3/] The situation in the northeast part of the State has changed since 1976. A large, wood-fired boiler has been installed at a pulpmill at Wallula, Washington. Contracts for hog fuel have no doubt greatly reduced the unused volume in the surrounding area.

[3/] This map and the one shown in figure 3 indicate the quantity of mill residues, by volume class, tributary to various locations within the 50-mile-radius supply zones noted. The volumes are not additive, however, since the supply zones overlap. Thus, care must be taken in assessing the number of opportunities for generating energy in the State.

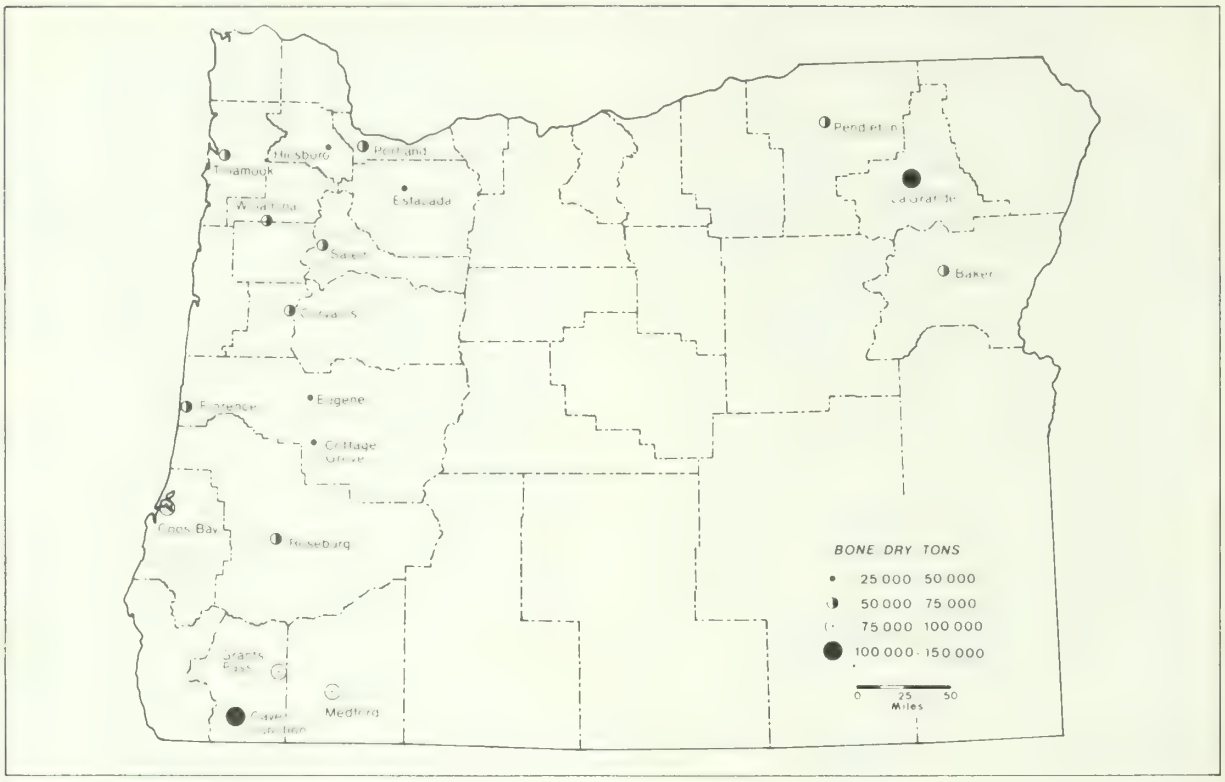


Figure 2.--Quantity of unused mill residues within 50-mile supply zones of selected cities.

To put these quantities in perspective, a 50-MW powerplant would require about 250,000 bone-dry tons of hog fuel annually (operating at 75 percent of capacity). As figure 2 shows, no location in Oregon has this quantity in its supply zone. The 50-mile supply zone was the consensus from various studies as a reasonable distance for wood residues to be transported to a central energy facility. In practice, residues are transported farther than 50 miles; the end value of the final product is the determining factor.

As the value of energy products increases it is likely that residues now used for low-value products, such as mulch and decorative bark, may be used for energy. Although all residues now used for miscellaneous purposes, as defined by the 1976 Oregon industry survey (*33*), may not be available for energy, some will be bid away from other uses. Figure 3 indicates the volume of "unused" plus "miscellaneous use" residues for a 50-mile supply zone. These volumes represent physical existence only. Competing uses and the difficulty of securing long-term contracts will considerably reduce the volume available for energy in today's economic environment.

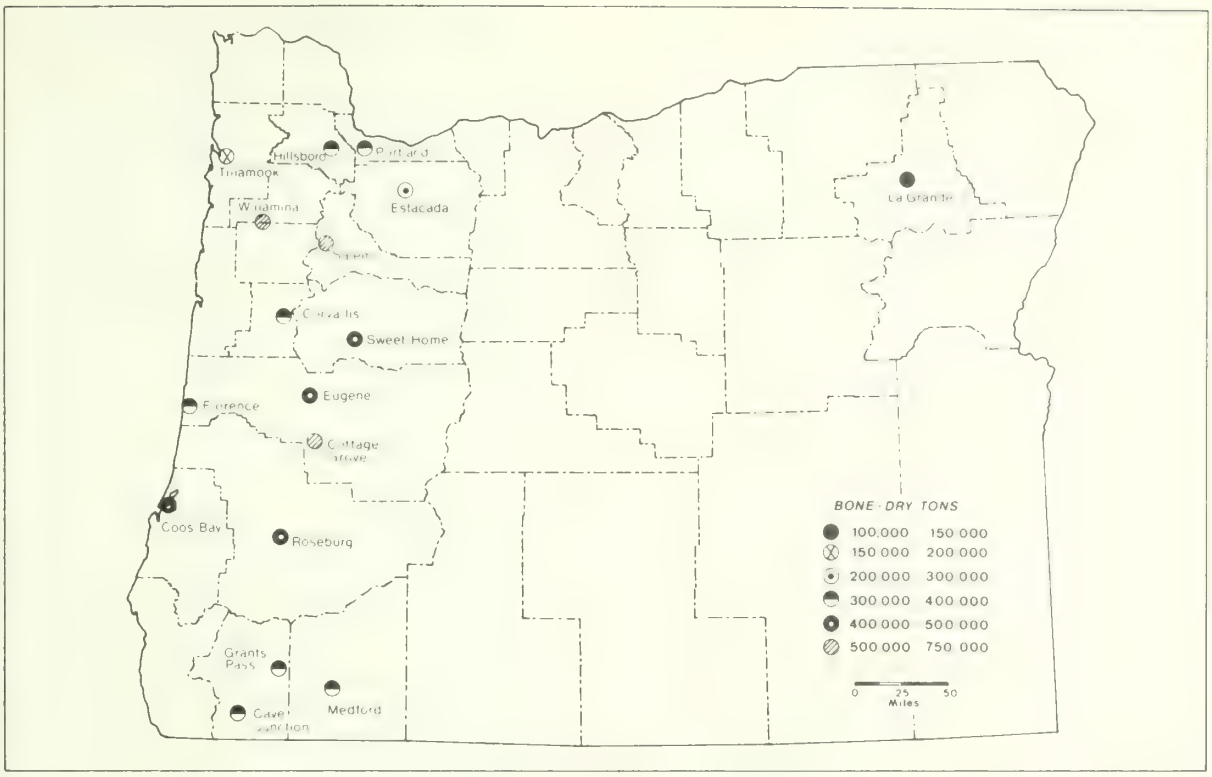


Figure 3.--Quantity of unused and miscellaneous use mill residues within 50-mile supply zones of selected cities.

Cogeneration within the forest products industry in the Pacific Northwest is a likely candidate for immediate additions to the area's supplies of electricity. Within the forest products industry, large volumes of residue are used as boiler fuel, about 4.3 million tons in 1976 (*33*).[4/] In plants where steam is now produced, generation of electricity would require less additional input than at a central powerplant. Thus, significant opportunities exist to generate electricity--coupling residues presently used for boiler fuel with those now unused or used for low-value miscellaneous purposes. Although cogeneration may not be feasible for each mill, it may provide a physical or economic alternative for clusters of mills close to each other.

Cogeneration will probably increase in importance in this region. Difficulty in securing adequate supplies of residues may restrict expansion for some mills. In addition, competition from conventional products and other types of energy will impact the level of electrical output in the future.

[4/] Although a portion of the total volume of residues used for fuel was consumed outside the industry or for general heating, by far the majority was used for boiler fuel.

Logging Residues

The volume of logging residues throughout the Pacific Coast is very high and represents significant potential for production of energy (*8, 27*). The main concerns are not about total volume, however, but of cost and future availability. The latter is a factor of increased utilization of residues for conventional products and a shift from old-growth to young-growth forests.

Three characteristics distinguish logging residues from mill residues as a resource base for energy. First, they are not in a readily usable form. At the minimum, chipping would be required. Second, they may have to be yarded to a loading point before they are prepared or transported-a relatively high cost to be borne by low-value products, such as energy. Finally, they are usually located some distance from processing facilities and thus incur higher costs for transportation. The fact that residues are not used for higher value conventional products says much about the economics of their use for energy.

Most studies of the energy potential of residues are using out-of-date information. The major point, however, is still valid; large quantities of logging residue exist if the means can be found to utilize them in an economically viable manner.

Data for the 1980 national timber assessment indicate a total of 181 million cubic feet of logging residues are generated annually in western Oregon (*32, 64*). For eastern Oregon the total is 26 million cubic feet. Converted to weight on the basis of 25 pounds per cubic foot (dry basis), the total for Oregon is over 2.6 million tons; this figure refers only to the growing-stock portion of logging residues. The non-growing-stock[5/] portion is roughly equal to the growing-stock portion. Thus, the total volume for Oregon expands to about 5 million ovendry tons annually.

Also not taken into consideration is the material less than 4 inches in diameter. Little definitive work has been done on measurement of total biomass of logging residues. Data from a recent study give a hint of the possible magnitude(*50*); from information compiled from various sources, the main-stem portion of logging residues is estimated to be slightly less than 50 percent of total biomass. By this standard, total biomass of logging residues in Oregon would be approximately 10 million dry tons. Maintenance of site productivity, however, requires leaving some material on the ground. Suffice it to say there is a considerable volume of material that could be converted to energy or related products. The 10 million tons quoted above could fuel forty 50-MW plants for a year.

[5/] Volume from previously dead, cull, or noncommercial trees on harvested areas.

Estimates of costs of removing logging residues range from $20 to $40 per ton, depending on various physiographic and technological factors. This is equivalent to 16-40 mills per kilowatt hour (*38, 50*). Add to this the costs of transporting, preparing, and processing the residues and it becomes apparent that production of electricity from logging residues is at a disadvantage in today's market, where it must compete with prices that include large quantities of cheap hydropower. Even if the above costs are conservative, electric power--or almost any energy product--cannot compete with the average cost of conventional sources. A change in the existing pricing system for electricity would make the situation more favorable. But even this would prompt use of more readily accessible sources, such as mill residues. Sharing the costs of removing residues, up to the benefits to land management, will be discussed later.

The situation surrounding logging residues is dynamic and presents problems in projecting future volumes. Increased demand from conventional products, more efficient techniques and equipment for harvesting timber, and a shift toward young growth will act to reduce future volume and concentration of residual materials. This uncertainty about future supplies presents special problems for central power facilities for capital investments with long payoff periods. Investors are reluctant to finance construction when long-term supplies of raw material are in doubt.

Mortality

It is doubtful that naturally occurring mortality, because of generally low concentrations per acre, will be a major factor in this region's energy picture. If a significant market for energy existed, there might be greater utilization of lower quality logs.

Catastrophic mortality, on the other hand, may make significant contributions to future needs for energy. In the case of major fires, salvage for conventional products may account for most of the volume. There may be, however, greater volumes of residue created by milling of these trees.

Epidemics of insects or disease, such as the tussock moth and mountain pine beetle outbreaks in northeast Oregon, offer substantial opportunity for production of energy. Studies by Oregon State University indicate that insects have killed approximately 1.3 billion board feet of timber in the Blue Mountain area over the past few years (*12, 70*). Much of this volume has value for solid products and pulp chips. Some of the material is not suitable for these products but has much value for energy products. This proportion will increase as the trees deteriorate in quality over time. A multiproduct operation, including energy, would be a most likely approach to utilizing this fairly large volume of timber. Such a facility, however, must be predicated on assurance of obtaining adequate supplies of dead timber for many years.

It has been estimated that timber killed by insects in northeast Oregon will be physically available for energy for 20 years. Thus, an energy-producing facility could be established with an adequate supply of material for a period long enough to write off the investment. This alternative, along with proposals for overcoming institutional constraints to long-term contracts, is being considered in a study by Oregon State University funded in part by the U.S. Department of Energy.

Hardwoods

Hardwoods, particularly on the west side of the Cascades, currently represent a little used resource. Many forest managers consider hardwoods an impediment to management of more desirable softwoods. Although some mills process hardwoods, mainly red alder, the timber inventory is enormous when compared with harvest. A recent survey of the forest industry (*33*) shows that only 65.5 million board feet (about 13 million cubic feet) of hardwoods were utilized in 1976. Recent inventories of western Oregon (*3, 35, 49*) show a roundwood volume of 4.8 billion cubic feet. As can be seen, the harvest is less than one-third of 1 percent of inventory volume.

The inventory figure stated above does not represent the total biomass of hardwoods, nor does it include volume on noncommercial land. From the little solid data existing, the total biomass of hardwoods is estimated at roughly one-and-two-thirds times the reported inventory volume. By this rough rule of thumb, the total volume of hardwoods suitable for energy is over 8 billion cubic feet. All of this volume, of course, is not available for energy-or other products, for that matter. Many private owners may not offer timber for sale at any price, much less at prices low enough to make energy products economically competitive. Some of the better quality timber will be used for higher value products, such as furniture. In addition, scattered pockets of hardwoods may not be economically retrievable. Even one-half of the available volume, however, could support five 50-MW electric plants for 30 years.

Hardwood stands are presently being converted to softwood in some areas. This is a costly practice but deemed necessary by those land managers desiring to return these productive lands to softwood types. The availability of energy markets for the bulk of this material might provide an impetus for increased stand conversion. Preliminary estimates supplied by the Industrial Forestry Association indicate that 6,000 acres of hardwood were converted to softwood in 1977. This figure is considered somewhat conservative and includes only lands owned by forest industry. There are about 2,700,000 acres of hardwood type in western Oregon. Obviously, all areas will not be converted to softwoods. Yet, a large portion of the area will yield greater volumes in the long run if hardwoods are converted to coniferous species and produce fuel for energy in the process.

It is obvious from these figures that significant potential exists to augment regional supplies of energy through increased use of the hardwood resource.

Silvicultural Materials

Residues generated during silvicultural operations (thinning, stand release, or site preparation) may serve as a source of raw material for production of energy. Some estimates are available for acres treated by these practices, but little is known about volume removed. Even less is known about the total biomass treated.

Advances in technology aimed at utilization of the whole tree may increase the quantity of material available for energy. The opportunities lie with greater recovery of fiber content through removal of the entire tree. Relogging of treated areas is generally not feasible because of potential damage to residual trees. For treatments such as site preparation, reentry may be impractical unless done before the new stand is established. In general, additions to raw material supplies for energy will be from tops and branches of trees and from trees currently below commercial size. A new market for this type of material, such as for energy, could provide the impetus for increased silvicultural activities. A major question, however, is how much material could be removed without deleterious effects on levels of soil nutrients(*42, 43*).

Brush Species

A large quantity of brush exists on forest lands throughout the Pacific Coast States. Many of these areas require treatment to return the site to full productivity. It is doubtful, however, if much of this type of material will be converted to energy in the near future. Little is known about the cost of removing and handling brush or the equipment necessary to accomplish the task. Another unknown is the factor brush plays in maintaining nutrient levels of the soil. Many questions would have to be answered and the economics improved before brush could be considered as a source of supply for energy in this area.

Biomass Farms

The use of short-rotation tree farms to provide wood for energy has gained much attention in the past few years (*9, 20, 50, 57, 60, 61, 71*). The concept entails intensive short rotation (usually 2-15 years) management of closely spaced, fast-growing trees. Hardwoods are most frequently considered because of their ability to propagate by coppicing.

Results of studies of species indigenous to the Northwest indicate yields from 4 to 33 tons (dry weight) per acre (*15, 23, 29, 45, 50, 60*). Yields of 10 to 20 tons per acre were frequently recorded. A shortcoming of most of these studies is the relatively small sample plots--some were only one-thousandth of an acre. There is some doubt whether these levels can be sustained on larger areas (*20*).

A number of issues remain unanswered concerning the concept of plantations for energy. The costs of large-scale plantations have yet to be established. Unknowns include the requirements and costs of fertilizing, irrigating, and harvesting. There is some uncertainty as to the success of repeated coppicing. Planting a new crop would increase costs significantly. Another factor relevant to the broad issue of alternative sources of wood for energy is the net energy balance of plantations. A major concern here is the potential dependence on petroleum-based fertilizers.

Technically, energy plantations are feasible. Their application centers around economics and development of necessary equipment. Possibly a more crucial question is that of availability of land. The data below provide a reasonably good estimate of land requirements for a 150-MW powerplant (*20*).

Sustained-yield productivity and land needs for a 150-MW power unit

Ovendry tons per acre per year	Acreage required
1	620,000
5	120,000
10	62,000
15	41,000
20	31,000

As can be seen, even with high, sustainable yields acreage requirements are high. Smaller facilities would obviously require less acreage. The problem of land availability comes into focus when specific locations are considered. Gentle terrain with adequate water supplies are paramount for success. In the Northwest most areas fitting this description are currently producing other crops or are within urban zones. Many areas in eastern Oregon, although having moderate slopes, suffer from restricted water supplies (*50*); where available, warm water from industrial processing, such as from pulpmills or thermal powerplants, could be used for irrigation of plantations.

A study in Washington should provide data for answering some of the above questions (*59*). This study was conducted in powerline rights-of-way. Utilizing the productive potential of these nonproducing lands could add valuable acreage to the region's declining commercial forest land base. The study was designed to produce cost and yield data for a number of management regimes on 1/4-acre plots, somewhat larger than in most studies.

Biomass farms offer advantages over other forms of fiber production through increased efficiency of harvesting, short waiting periods for cash flows, and lower regeneration costs via coppicing. Chief disadvantages are higher costs per acre for establishment and management, restrictions on available land, genetic problems associated with monoculture, and the impact of devastation by fire or wind or outbreaks of insects or disease.

Few studies indicate short-term application of large-scale energy plantations in the Northwest. Major determinants are cost and availability of underutilized sources, such as logging residues. The opportunity may be best for an independent energy facility desiring a guaranteed supply of raw materials.

Materials Handling

Preparation

Most systems for converting wood to energy have strict requirements concerning the size, form, and moisture content of wood or bark fuels. Most sources of wood, mill residues being the usual exception, must be modified to some degree to meet these requirements(*39*). Roundwood is usually hogged or chipped to produce what is called hog fuel. This is not a common practice, however, as mill residues currently meet most of the demand for energy. Wetter types of hog fuel are usually passed through a drying phase to attain the desired moisture content. Hog fuel from mill residues are frequently dry enough to avoid this phase; however, water absorption during storage may present problems. Drying of large quantities of hog fuel is a problem in terms of cost and time. Some integrated systems use the fines (sawdust, for example) to fire drying furnaces or modular units, such as the cyclone burners previously discussed. Some fluid-bed reactors do not require all material to be dried if a proper mix of high- and low-moisture content feedstock is maintained.

Drying of fuels is a critical factor in determining efficiency of the overall process. Corder (*11*) indicates heat loss of 13 percent for wood fuel at 100-percent moisture content (dry basis), and 26 percent at 200-percent.[6/] In addition to causing a loss of realized heat, excess moisture acts to retard combustion. Difficulty in maintaining combustion occurs when the moisture content exceeds 200 percent.

Suspension burners, such as will be used by PGE's Boardman coal plant now under construction, require that the feedstock be reduced to fine particles. This is usually accomplished by hammermilling and screening. The added costs, however, reduce the competitiveness of wood compared with more easily pulverized fuels, such as coal--sawdust and sander dust being exceptions.

Densification of wood fiber by pelletizing has recently received much attention. In this process, wood--usually hog fuel--is dried and compressed into cylindrical pellets. Based on early findings, major advantages of this procedure are uniformity in size and moisture content, reduced storage requirements, and clean burning. Pelletizing is not required for some conversion systems and represents an unnecessary cost. On the other hand, the pellets are ideally suited to the needs of small installations, such as those in schools or hospitals for direct heating or steam production.

[6/] All moisture contents are stated in terms of dry basis; that is, the weight of water relative to the weight of the wood portion. These moisture contents can be converted to wet basis by the following formula:

$$MC(wet) = \frac{100\ [MC(dry)]}{100 + MC(dry)}.$$

There is some evidence that the resins in bark provide some of the adhesive agents that assist in preventing physical deterioration of pellets. Thus, it may be necessary to mix bark with wood residues from some manufacturing operations. Normally, hog fuel contains more than an adequate proportion of bark. Bark also increases the value of pellets because of its higher heat value compared with wood.

Analysis of the long-term potential of pelletizing is hampered by lack of available operational data and costs. Figures quoted at a recent hearing in Eugene indicate the cost of pellets to be about $20 to $24 per dry ton, f.o.b. mill--about three to five times higher than hog fuel, at $5 to $7 per dry ton. It does compare favorably with Wyoming coal at $20 per ton, which has approximately the same heating value per pound.

Transportation

Unless a source of fuel, such as onsite mill residues, is adequate for all energy needs, transportation of materials is a major factor in determining economic feasibility of energy production. Four modes of transportation are usually given consideration for movement of wood: trucks, railroads, pipelines, or conveyor systems. Barges have been considered but are limited to facilities on or near a navigable river.

Trucking usually costs least and is most adaptable for transporting wood fuels. Trucks are flexible enough to reach remote locations and handle small quantities of fuels. The extensive road network favors the use of trucks over other transportation with more restricted avenues of movement. In the case of in-woods chipping, trucks offer the only reasonable alternative. Trucks are also better able to meet the fuel needs of an immediate increase in energy production. Trucking costs are somewhat site specific, depending on type of roads, discounts, tax structure, contract specifications, and equipment. Average costs used in various studies range from 10 to 17 cents per ton-mile. One component of this cost being given careful consideration is the weight-mile tax currently levied against all hauling of commodities. This tax tends to favor high-value products over low-value products, such as hog fuel. Various political bodies are examining this tax in terms of its impact on use of wood for energy. A reduction in the tax would obviously reduce costs and thereby increase the competitiveness of wood as a fuel.

A study in Vermont (*30*) considered the merits of trucks versus railroads for hauling chips to a central power facility. Complete use of rail systems and trucking to dispersed railheads were examined. Trucking was concluded to be the cheaper of either rail-oriented option. Much of the cost differential was attributed to the additional handling of the chips between trucks and railcars.

Hauling of hog fuel by rail is currently practiced, primarily to move mill residues. This is a viable alternative where processing facilities lie on an existing rail network. Building of spur lines would be prohibitive for most energy-related operations.

Use of rail delivery for energy production might be favored at large-scale central facilities but not for widely scattered, small-scale ones. The general push, at least politically, is for decentralized production of energy. Thus, the use of railroads to haul fuels would be less advantageous. The key here is the cost associated with delivery and handling of materials from woods or concentration yard to railhead. Smaller facilities could best be served by trucks loaded in the woods where reloading into railcars would not be necessary. Larger facilities, requiring a greater volume of fuel, could reach farther and thus amortize the reloading costs over greater distances. This would enable them to use a rail system if one was close.

Conveyor belts are frequently used for onsite movement of residues within the forest products industry. Conveyor systems in excess of 1 mile in length are used to move chips between adjacent processing centers. The major disadvantages to the use of conveyors are cost and inflexibility. Costs of installation are high, especially when rights-of-way must be secured. Although these systems can be moved, time and cost are a major consideration. Figures from a recent study of energy plantations (*50*) place the cost of installing a conveyor system at $250 per foot. At this rate, the installation cost of 1 mile of belt would exceed $1.3 million.

Pipelines are also expensive and are stationary. Some consideration was given to construction of a pipeline for transporting Wyoming coal to eastern Oregon. Actions were deterred by relatively high costs of construction and difficulty in obtaining permission for access along the proposed route. An additional problem associated with pipelines is the requirement for large quantities of water. For example, movement of 1,400 tons of chips would require about 2 million gallons of water (*66*).

Storage

Problems in storage of wood generally relate to the scale of operation and rotation of inventory to avoid deterioration. Fewest difficulties are encountered when materials are used at the same location and time as they are created. This obviously eliminates the need for storage areas, except as a safeguard against shutdown of the residue-producing facility. Therein lies the advantage of the forest products industry as generator of energy from mill residues.

Deterioration of wood fuels depends mainly on length of time in storage and degree of protection from the elements. Potential problems can be mitigated by proper rotation of the inventory. Other problems encountered in storage are fires, freezing of materials in colder climates, and increased moisture content from precipitation. Where materials are constantly being created, such as in the forest products industry, these problems or their impacts are not as significant.

Institutional Factors of Energy Production

Many institutional factors affect new sources of energy. Some are local, and others are national with political origins. Some of the significant problems are summarized below.

Marketing of both energy and fuel supplies are an area of major concern. The current pricing structure of electricity, for example, does not favor generation by nonutility companies. Few new sources of energy can compete with the existing prices which are average prices from existing sources, including low-cost hydropower. Private utilities will purchase some power but at prices as low as one-tenth of its market value. Marketing of power through the BPA grid is possible where customers can be found, usually in California. This entails a marketing fee of about 3 mills/kWh which further reduces the competitiveness of new sources. A generally more positive approach to marketing of small-scale power and the use of roll-in pricing would open the door to greater production of electricity by nonutility companies, especially the forest products industry. BPA is currently giving some attention to this situation. Enactment of statutes giving BPA power to purchase energy is being considered.

On the other side of the coin is the supply issue. Securing an adequate supply of wood is a problem voiced by most potential producers of energy. Development of a contractual procedure by which public landowners could insure a long-term supply of underutilized material would be a major breakthrough. The prospects for this do not look bright. There is no legal framework for this type of action, and competition from other uses of wood is a complicating factor. A similar environment exists in the industrial sector. A recent study of the Eugene area (*46*) indicated a general reluctance on the part of millowners to enter into any type of long-term contract to supply residues for energy production. At best, some of the suppliers would agree to a year-to-year basis, leaving the price negotiable. This situation does not favor construction of an energy facility with a writeoff period of 15 to 30 years.

Existing tax structures also affect the energy situation to a great degree. Placing privately financed energy facilities on the property tax rolls increases costs of production. The question raised here is whether these facilities are in fact pollution control efforts which enables them to be placed in a tax exempt status (*66*). A policy favoring the use of biomass for energy might require a major overhaul in property tax laws. Changes in State and Federal tax laws governing depreciation of capital investments could have positive effects on production of energy by nonutility companies.

Incentive programs have been and will continue to be an important means for stimulating research and development of various forms of energy. Much of the effort in this area has been focused on high technology solar energy, which has little impact on the use of biomass. Increasingly, however, efforts have been stepped up by the U.S. Department of Energy and other agencies to stimulate research into the use of wood for energy. Although incentive programs are valuable tools, economics is the overriding factor in terms of adaptation of technology. The message is that the product must be competitive and profitable. These criteria, for example, apparently are not met by methanol production from wood at this time.

A topic being discussed is sharing the cost of removal of raw material to the extent of benefits to the land or landowner. A case in point is logging residues on National Forest lands. It appears that the cost of removing these residuals for energy uses is currently too high to be supported by prices for energy. In many cases this material must be treated, frequently at rather high costs, to prepare the land for the next crop of trees. Investigations have been made into development of a cost-sharing program to allow for payment for removal of these materials, at least to the level of current costs of treatment. Whether or not this would make the price of wood-based energy competitive is unknown. The main concern again might be guarantee of supply.

Summary

Insuring an adequate supply of energy for the future is a concern that affects almost everyone. The national and worldwide environment of nonrenewable sources dictates impending changes in our patterns of producing and consuming energy. Greater diversity in sources of energy is paramount to progress toward meeting this country's enormous appetite for energy. Solar, nuclear, and fusion technologies hold much promise for the long term; coal plays a potentially important role in the short-term future. The use of this region's abundant biomass, however, may be prominent in the interim before these high-technology alternatives make significant contributions.

Utilization of biomass for energy may occur in two forms. Most obvious is the direct generation of energy from various sources of biomass. An indirect approach would be the substitution of wood for more energy-intensive materials, such as iron or aluminum. The impact of these actions is largely unknown; the direction taken will be, to a great extent, a matter of national policies and economics. Regionally, the use of wood for generation of electricity appears to be the most likely alternative. Cogeneration by the forest products industry will be the probable vehicle for this output. The production of low Btu gas may become a factor if national legislation restricts industrial use of natural gas. Analysis of the energy potential of wood is not just a matter of electricity generation but which of a wide

variety of energy products offers the greatest advantage to the Nation and the region.

The opportunities for producing energy are predicated on the vast quantities of biomass in the Pacific Coast States. Some of this material has received special attention because of its current status of underutilization. Such is the case with logging residues and insect-killed trees in eastern Oregon. No single source of wood fiber, however, has to supply all the needs of an energy conversion facility. In the broadest sense, there is an abundance of wood fiber having potential for producing energy. Physical availability is not the real issue--rather the question is one of economic availability and marketing. Other restrictive factors are competition from the use of wood for conventional products and the relative cost of other sources of energy. Techonology will, of course, affect the rate at which wood sources will augment future supplies of energy.

An additional means of affecting future supplies of energy is through conservation. Effective conservation in the use of energy might temporarily dampen efforts to produce energy from woody biomass. On the other side of the issue, substitution of wood for more energy intensive products would increase demand on a dwindling resource. This potential shift in emphasis toward solid products would probably decrease the quantity of wood now considered a source for production of energy(*25*). The extent to which conservation will be effective is, to a large degree, a policy issue and a matter of educating the public. There is one certainty: Demand for energy will continue to grow. With attention being given to use of renewable resources, the forests of the Pacific Northwest will be expected to supply energy and greater quantities of all wood-based products.

Literature Cited

1. American Petroleum Institute. 1978. Alcohols, a technical assessment of their application as fuels. Publ. 4261 (July), 32 p.

2. Barkley, J.F., and R.E. Morgan. 1950. Burning wood waste for commercial heat. Bur. Mines Inf. Circ. 7580, 12 p.

3. Bassett, Patricia M. 1977. Timber resources of southwest Oregon. USDA For. Serv. Resour. Bull. PNW-72, 29 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

4. Bonneville Power Administration. 1977. Alternative energy system for the home. Bookl. 4, Inf. Ser., Living in a glass house. U.S. Dep. Energy. 15 p.

5. Botterill, J.S.M., and M.J. Virr. 1977. The contribution of fluid-bed technology to energy savings and environmental protection. Appl. Energy (3):139-149.

6. Brink, David L. 1976. Pyrolysis-gasification-combustion: A process for utilization of plant material. Appl. polyma Symp. 28:1377-1391.

7. Brown, Owen D. 1977. Energy generation from wood-waste. 18 p. Governor William G. Millikens Conf. Wood Energy, Nov. 29, Ann Arbor, Mich.

8. Burgess, Robert L. 1978. Potential of forest fuels for producing electrical energy. J. For. 76 (3):154-157.

9. Burwell, C.C. 1978. Solar biomass energy: An overview of U.S. potential. Science 199(March 10):1041-1048.

10. Cherewick, H.R. 1975. The energy burner system. Pulp and Pap. Can. 76(7):58-61.

11. Corder, Stanley E. 1973. Wood and bark as fuel. Oreg. State Univ. Res. Bull. 14, 28 p.

12. Currier, Raymond A., Dennis P. Dykstra, Robert O. McMahon and Stanley E. Corder. 1978. Potential energy uses for diseased and beetle-killed timber and forest residues in the Blue Mountain area of Oregon. DOE Rep. RLO/2227/T33-1, 58 p.

13. Deardorff, Don. 1975. Direct combustion systems. Wet wood waste as a viable fuel supply. *In* Wood residue as an energy source. For. Prod. Res. Soc. Conf. Proc. P-75-13, p. 89-91.

14. Douglas, E. 1975. Conversion of wastes to energy by pyrolysis. *In* Environmental problems, vol. 2, p. 218-220. (Proceedings of a seminar organized by the senior advisors to United Nations Economic Commission for Europe, Sept. 1-6, Hamburg, Ger.)

15. Ek, Alan R., and David H. Dawson. 1976. Actual and projected growth and yields of populus "Tristis #1" under intensive culture. Can. J. For. Res. 6:132-144.

16. Electrical World. 1977. California PUC studies cogeneration. Electr. World (April 15), p. 29.

17. Ellis, Thomas H. 1975. Should wood be a source of commercial power? For. Prod. J. 25(10):13-16.

18. Erlandson, Sven. 1977. Why should the pulp and paper industry generate electric power. Pulp and Pap. Can. (April):S-20 to S-21.

19. Evans, R.S. 1977. Energy self-sufficiency prospects for the B.C. forest products industry. Can. For. Serv. West. For. Prod. Lab. Inf. Rep. VP-X-166, 19 p.

20. Evans, R.S. 1974. Energy plantations--should we grow trees for power plant fuel? Can. For. Serv. West. For. Prod. Lab. Inf. Rep. VP-X-129, 15 p.

21. Furman, Lloyd H., and Leland G. Desmond. 1976. Wood residues for veneer drying, a case history. For. Prod. J. 26(9):52-55.

22. General Motors. [n.d.] Methanol: an automotive fuel in our future? White pap. 2 p. Res. Lab.

23. Gordon, John C. 1975. The productive potential of woody plants. Iowa State J. Res. Part 2, 49(3):267-274.

24. Grand Haven, Mich., Board of Light and Power. 1978. Supplemental wood fuel experiment. Interim rep., January 9.

25. Grantham, John B. 1977. Anticipated competition for available wood fuels in the United States. *In* Fuels and energy from renewable resources, chapter 3, p. 55-91. David A. Tillman, Kyosti V. Sarkanen, and Larry L. Anderson, eds. Acad. Press, New York.

26. Grantham, John B., and Thomas H. Ellis. 1974. Potentials of wood for producing energy. J. For. 72(9):552-556.

27. Grantham, John B., Eldon M. Estep, John M. Pierovich, and others. 1974. Energy and raw material potentials of wood residue in the Pacific Coast States: A summary of a preliminary feasibility investigation. USDA For. Serv. Gen. Tech. Rep. PNW-18, 37 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

28. Hammond, V.L. 1974. Energy from forest products residuals--gasification of wood waste. Am. Pulpwood Assoc. (Jan.):89-96.

29. Heihman, P.E., D.V. Peabody, Jr., D.S. DeBell, and R.F. Strand. 1972. A test of close-spaced, short-rotation culture of black cottonwood. Can. J. For. Res. 2:456-459.

30. Henningson, Durham and Richardson, Inc. 1977. Burlington, Vermont refuse-wood power plant, aquaculture, greenhouse--a conceptual study. Washington, D.C.

31. Hickman, H.L., Jr. 1975. Energy recovery from municipal solid waste in the United States. *In* Environmental problems, vol. 2, p. 251-258. (Proceedings of a seminar organized by the senior advisors to United Nations Economic Commission for Europe, Sept. 1-6, Hamburg, Ger.)

32. Howard, J.O. 1973. Logging residue in Washington, Oregon, and California, volume and characteristics. USDA For. Serv. Resour. Bull. PNW-44, 26 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

33. Howard, James O., and Bruce A. Hiserote. 1978. Oregon's forest products industry--1976. USDA For. Serv. Resour. Bull. PNW-79, 102 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

34. Ince, Peter J. 1977. Estimating effective heating values of wood and bark fuels at various moisture contents. USDA For. Serv. Gen. Tech. Rep. FPL-13, 8 p. For. Prod. Lab.

35. Jacobs, David M. 1978. Timber resources of west-central Oregon. USDA For. Serv. Resour. Bull. PNW-76, 30 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

36. Jasper, M.T., and Peter Koch. 1976. Suspension burning of green bark to direct-fire high temperature kilns for southern pine lumber. For. Prod. Res. Soc. Workshop Proc. P-75-13, p.70-71. Denver, Colo.

37. Javetski, John. 1978. Washington fiddles while industry burns. Power 122(4):35-40.

38. Johnson, Leonard R., George Simmons, and James Peterson. 1977. Energy supply and environmental impacts--unconventional sources. Northwest energy policy project, study module 111-B. 275 p. Coll. For. Eng. Univ. Idaho, Moscow.

39. Johnson, Robert C. 1975. Some aspects of wood waste preparation for use as a fuel. TAPPI 58(7):102-106.

40. Katzen, R. and Associates. 1975. Chemicals from wood waste. USDA For. Serv., For. Prod. Lab. Publ. AN 441, Summary, 25 p.

41. Keller, F.R. 1975. Fluidized bed combustion systems for energy recovery from forest products industry wastes. For. Proc. Res. Soc. Annu. Meet. Proc., Denver, Sept., FPRS P-75-13.

42. Knight, H. 1966. Loss of nitrogen from the forest floor by burning. For. Chron. (June):149-152.

43. Likens, G.E., F.H. Bormann, R.S. Pierce, and W.A. Reiners. 1978. Recovery of a deforested ecosystem. Science 199 (Feb. 3):492-496.

44. Liu, M.S., and R. Serenius. 1976. Fluidized beds solids waste gasifer. For. Prod. J. 26(9):56-59.

45. Long, James N., and J. Turner. 1975. Above-ground biomass of understorey and overstorey in an age sequence of four Douglas-fir stands. J. Appl. Ecol. 12(1):179-188 from Coll. For. Resour., Univ. Wash., Seattle.

46. McMahon, Robert O. 1976. Mill and woods residues tributary to Eugene, Oregon available for steam generation. Oreg. State Univ. For. Res. Lab. Res. Bull. 20, 10 p.

47. Mallan, G.M., and E. I. Titlow. 1976. Energy and resource recovery from solid wastes. Resour. Recovery and Conserv. 1(1975):207-216, illus.

48. Matthews, S. LaMont. 1974. The practical aspects of using wood residue to power mills. For. Prod. Res. Soc. FPRS Sep. MW-74-539, 4 p.

49. Mei, Mary A. 1979. Timber resources of northwest Oregon. USDA For. Serv. Resour. Bull. PNW-82, 29 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

50. Mitre Corporation. 1977. Silvicultural biomass farms. MITRE Tech. Rep. 7347, Vol. 1-6.

51. Mobil Oil Corp. 1977. Methanol and ethanol as fuel intermediates. White pap., 13 p. Cen. Res. Div.

52. Moody, D. R. 1976. Advances in utilizing wood residues and bark as fuel for a gas turbine. For. Prod. J. 26(9):52-55.

53. Moore, William E. 1976. Wood residue energy conversion systems market. For. Prod. J. 26(3):23-28.

54. Nanney, William M., and Floyd C. Gustafson. 1975. Large bark and wood waste fired boiler--a case history. Weyerhaeuser Co., Tacoma, Wash.

55. Neal, Gordon W. 1971. Advantages of combined power/process generating plants. Power Eng. (Feb.):56-59.

56. Pacific Northwest Utilities Conference Commission. 1978. West group forecast of power loads and resources, July 1978 - June 1989. March 1, 1978.

57. Rose, D.W. 1977. Cost of producing energy from wood in intensive cultures. J. Environ. Manage. 5:23-35.

58. Saeman, Jerome F. 1978. Statement before the U.S. Senate Appropriation Committee Hearing on Alcohol Fuel. Jan. 31, 1978, 11 p.

59. Seattle City Light. 1978. Technical proposal, research and development of fuels from woody biomass. Seattle City Light. Off. Environ. Aff. PRDA 4126 (Jan. 30), 117 p.

60. Sezego, George C., and Clinton C. Kemp. 1974. The energy plantation. For. Prod. Res. Soc. FPRS Sep. CC-74-550, 15 p.

61. Sezego, George C., and Clinton C. Kemp. 1973. Energy forests and fuel plantations. Chemtech 3:(May):275-284.

62. Stone, Charles L. 1976. Energy from waste. Background report in Senate Bill 1395 of the Joint Committee on Job Development, Calif. State Legislature. Dec. 372 p.

63. U.S. Department of Agriculture. 1978. Agricultural situation (monthly) crop reporting board. Econ. Stat. and Coop. Serv. Vol. 62 No. 3, 16 p.

64. U.S. Department of Agriculture, Forest Service. 1978. Forest statistics of the U.S., 1977: --all data subject to revision. 133 p.

65. U.S. Department of Agriculture, Forest Service. 1973. The outlook for timber in the United States. USDA For. Serv. For. Resour. Rep. 20, 367 p.

66. University of Oregon and Oregon State University. 1978. Oregon solar planning study report to U.S. Dept. of Energy and Oregon Dept. of Energy by Univ. of Oregon and Oregon State Univ., March 1. 219 p.

67. Voss, George D., and Victor A. Gauzer. 1977. Gasification of wood residues. Paper presented at Forest Products Research Society annual meeting, July, 13 p., illus. Denver, Colo.

68. Wahlgren, H. Gus, and Thomas H. Ellis. 1978. Potential resource availability with whole-tree utilization. TAPPI 61(11):37-39.

69. White, Vernon S. 1973. Plywood plant reduces fuel costs while solving waste disposal problems. For. Ind. 100(1):62-63.

70. Wilkinson, John L. 1977. Economic uses for timber killed by the mountain pine beetle in northwest Oregon. White pap., Oreg. State Univ. Dep. For., p. 12. Corvallis.

71. Young, Harold E. 1978. Forest biomass inventory: The basis for complete-tree utilization. For. Prod. J. 28(5):38-41.

METRIC EQUIVALENTS

1 cubic foot = 0.283 cubic meter
1 pound = 0.454 kilogram
1 ton = 0.907 metric ton

1 mile = 1.609 kilometer

1 acre = 2.47 hectares

1 British thermal unit (Btu) = 1 055.87 joules

1 kilowatt hour (kWh) = 3.6×10^6 joules

GPO 989-095

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

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USDA FOREST SERVICE GENERAL TECHNICAL REPORT PNW-95
OCTOBER 1979

PHOTO SERIES FOR QUANTIFYING FOREST RESIDUES IN THE:

SIERRA MIXED CONIFER TYPE
SIERRA TRUE FIR TYPE

WAYNE G. MAXWELL
FRANKLIN R. WARD

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ABSTRACT

Five series of photographs display different forest residue loading levels, by size classes, for areas of like timber type (Sierra mixed conifer and Sierra true fir) and cutting objective.

Information with each photo includes measured weights, volumes and other residue data, information about the timber stand and harvest actions, and assessment of fire behavior and suppression difficulty.

These photo series provide a fast and easy-to-use means for quantifying and describing existing and expected residues.

KEYWORDS: Residues, residue management, fuel hazard rating, fire behavior (forest), slash (Sierra mixed conifer), slash (Sierra true fir), residue measurements, residue surveys.

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This publication was developed by the Pacific Northwest Forest and Range Experiment Station and Region 5, Forest Service, U.S. Department of Agriculture, in cooperation with the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, and State of California, Department of Forestry, to serve the needs of forest land managers in the Pacific Southwest.

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LIST OF PLANT SPECIES CITED

California black oak	*Quercus kelloggii* Newb.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
grand fir	*Abies grandis* (Dougl.) Lindl.
incense-cedar	*Libocedrus decurrens* Torr.
Jeffrey pine	*Pinus jeffreyi* Grev. & Balf.
ponderosa pine	*Pinus ponderosa* Laws.
red fir	*Abies* spp.
sugar pine	*Pinus lambertiana* Dougl.
western white pine	*Pinus monticola* Dougl.
white fir	*Abies concolor* (Gord. & Glend.) Lindl.

METRIC CONVERSIONS

1 acre	= 0.404 7 hectare
2.471 acres	= 1 hectare
1 cubic foot	= 0.283 2 cubic meter
35.31 cubic feet	= 1 cubic meter
1 foot	= 0.304 8 meter
3.281 feet	= 1 meter
1 inch	= 2.54 centimeter
0.3937 inch	= 1 centimeter
1 ton (short)	= 0.907 ton (metric)
1.102 tons (short)	= 1 ton (metric)

WHAT ARE THESE PHOTO SERIES?

These photo series are arrays of photos; each array shows different residue loading levels generated from like timber types and cutting practices. Each photo is supplemented with information which includes:

- Measured quantities by size classes, average depth, ground area covered, and other residue data.
- Harvest information.
- Assessment of fire behavior and suppression difficulty.

Thus, the series provide a basis for quantifying and describing existing and expected residue loadings on other areas and serve as a communication link among users.

WHY ARE THEY NEEDED?

Timber harvesting, silvicultural practices, and land clearing operations annually generate forest residues on thousands of acres in the Sierra Nevada.

Although some residues are beneficial for nutrient cycling, soil protection, wildlife cover, and the microclimate, excessive residues adversely affect the forest environment in many ways. Much of the forest contains residues in undetermined quantities, which are

excessive from the standpoints of resource use, protection, and management. So that residues may be reduced to a level considered desirable, estimates are needed on quantities that now exist or will be created by some activity.

Inventory techniques, such as the planar intersect method, are useful when a high degree of accuracy is needed but are time consuming and costly to apply extensively. Photo series can be used to make fast, easy, and inexpensive quantifications of residue, adequate for most management needs.

There has been no way for all resource disciplines to become readily familiar with volumes and descriptions of residue so that they can make quantitative inputs to residue management. Likewise, because fuel rating systems are specialized and subjective, they too are not readily adapted to other environmental components. These deficiencies can be overcome with the photo series.

HOW CAN THEY BE USED?

Inventory of Down Residue

Loadings in various residue size classes, average residue depth, and ground area covered are characteristics that are visible in the photographs; hence, users can estimate any of these characteristics on an area being inventoried by comparing them with the photos as follows:

1. Observe each characteristic of the residue on the ground (e.g., 3.1- to 9-inch

2. Select a photo that nearly matches, or photos that bracket, the observed characteristic.

3. Obtain the quantitative value for the characteristic being estimated from the data sheet accompanying the selected photo (or interpolate a value between photos).

These steps are repeated for each characteristic desired. If the general area being inventoried has zones of obvious differences in residue loading, the user should consider making separate determinations for each zone; these can then be weighted and cumulated for the whole area.

Residue characteristics not distinguishable in the photographs are duff and litter depth, proportion of sound residue by species, and proportion rotted. If values for these characteristics are desired in an inventory, they must be derived from independent sampling or observations.

Inventory information can be used by land managers to (1) evaluate impacts residues have on various aspects of forest management, (2) identify areas of unacceptable residue loading, (3) identify priority areas for treatment, (4) estimate amount of utilizable material, and (5) predict characteristics of fire behavior and resistance to suppression.

Determination of Desired Residue Level

Land management objectives can be more nearly achieved if a team of appropriate specialists can participate in specifying residues that should remain onsite after completion of a cutting activity. Individuals helping with these determinations can study the photo series to recognize the appearance of various quantities and distributions of residue. With this knowledge, each individual can describe in quantitative terms the residue thought necessary to meet environmental concerns and goals of a particular specialty. The team can then use the photo series as a communication tool to resolve differences in arriving at a desired level of residue.

After treatment, the degree to which objectives were achieved can be judged by comparing observed posttreatment loading with the desired level description.

Prediction of Residues From Planned Cutting and Residue Changes From Treatments

Photo series are a rudimentary aid for predicting amounts of residue from cutting and changes in residue from treatments. Many factors, such as condition of timber stand, topography, logging method, and intensity of utilization, affect the volume of resulting residues. Therefore, users should bear in mind that these series depict only a few of the possible combinations.

To predict residue volumes from planned cutting, the user compares timber volume and size information from cutting plans with this kind of information in the photo series. Selecting a photo series level or levels with similar stand characteristics, the user refers to data sheet loadings, considers factors that differ from the photo series situations, and quantifies the loading expected.

Predicted loadings can be used to support changes in cutting and removal actions and to plan appropriate treatments.

To predict residue changes from treatments, the user studies the treated and untreated levels in the photo series to gain knowledge of relative changes or reductions affected by sample treatments. Then, comparing residue inventory or preharvest prediction information with levels in the series, the user predicts the change a specific treatment may produce.

Predicted change in residue from treatments can aid in (1) identifying treatments that will reduce residues to the desired level, (2) selecting the most cost-effective treatments, and (3) estimating tons that will be consumed by fire or removed in other ways. Improved accuracy in estimating tons consumed by fire will increase the reliability of calculations of emissions from particulates and chemical compounds.

HOW WERE THEY DEVELOPED?

Area Selection and Data Collection

Areas photographed for these series were selected to show typical residue loading variations resulting from commonly applied harvest and cultural practices in selected major vegetative types of the Sierra Nevada. Photos were taken and collected as follows:

1. Areas were photographed and the material in the photo area sampled in accordance with USDA Forest Service national guidelines.[1]

2. Measurements were made in accordance with the "Handbook for Inventorying Downed Woody Material."[2] Specific gravities used for calculating loadings are based on ovendry weights and air-dry volumes.

3. Information about timber stands, logging practices, and residue treatments were obtained from timber sale records in field offices or estimated on the site if such records were not available.

[1]U. S. Department of Agriculture, Forest Service. 1975. National fuel classification and inventory system, preliminary draft. 61 p., illus. Wash. Off., Washington, D. C.

[2]Brown, James K. 1974. Handbook for inventorying downed woody material. USDA For. Serv. Gen. Tech. Rep. INT-16. 24 p., illus. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Assessment of Fire Behavior and Suppression Difficulty

Quantities of dead and down fuel in each photo example were assessed for wildfire spread rate, flame length, and resistance to suppression, based on assumed conditions of 0- to 15-percent slope, 4-percent fine fuel moisture, and 10-miles-per-hour windspeed at 20 feet; procedures used were determined from fuel model scaling tables developed by Dr. David V. Sandberg, and a resistance to suppression matrix developed by Wayne G. Maxwell.[3]

HOW CAN THEY BE SUPPLEMENTED?

If users in the Pacific Southwest find they have important local residue loadings not adequately represented, they can supplement these series or develop additional series by following procedures described in the referenced documents. The series in this publication may be usable, in total or in part, in appropriate vegetative types in other regions.

These series do not show residue loadings in stands undisturbed by cutting activities. Natural residue photo series are being developed for inventorying such areas.

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[3]Unpublished data on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

HOW ARE LEVELS IN THESE SERIES CODED?

The data for each level are presented on the page facing the photo. Facing picture and data pages have the same code for the residue situation shown. The code shows:

a. Order of rank from lightest loading to heavist loading shown in the series of photographs.

b. Forest type; e.g., MC = mixed conifer, TF = true fir.

c. Forest size class, where:

1 = <5-inch d.b.h.

2 = 5- to 11-inch d.b.h.

3 = 12- to 20-inch d.b.h.

4 = >20-inch d.b.h.

d. Cutting practice, where:

RC = regeneration cut (clearcut, seed tree, shelterwood).

PC = partial cut (tree selection, group selection, overstory removal, understory removal, sanitation).

PC partial cut (tree selection, group selection, overstory removal, understory removal, sanitation).

EXAMPLE: 1-MC-4-RC is the first photo in the series for mixed conifer, >20-inch diameter trees, after harvest by regeneration cutting.

This report augments published photo series for residue levels in western forest vegetative types.[4]

[4] Maxwell, Wayne G., and Franklin R. Ward. 1976. Photo series for quantifying forest residues in the: Coastal Douglas-fir--hemlock type, coastal Douglas-fir--hardwood type. USDA For. Serv. Gen. Tech. Rep. PNW-51, 103 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Maxwell, Wayne G., and Franklin R. Ward. 1976. Photo series for quantifying forest residues in the: Ponderosa pine type, ponderosa pine and associated species type, lodgepole pine type. USDA For. Serv. Gen. Tech. Rep. PNW-52, 73 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

NOTE: The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval of any product or service by the U.S. Department of Agriculture to the exclusion of others which may be suitable.

MIXED CONIFER

SIZE CLASS 4

REGENERATION CUT

A SERIES OF 3 LEVELS

REMINDERS TO USERS:

1. The marker in these photos is 1 foot square, and the pole is painted in contrasting colors at 1-foot intervals to provide perspective.

2. Stumps are not included in residue quantities.

3. Rotted residue is that which would come apart or splinter when kicked.



DATA SHEET Residue descriptive code 1-MC-4-RC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.2	13
0.26- 1.0	2.6	174
1.1 - 3.0	4.8	385
3.1 - 9.0	4.3	360
9.1 -20.0	2.8	225
20.1+	0	0
Total	14.7	1,157

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.1
Ground area covered by residue 1/4-inch diameter and larger		(percent) 61
Average duff and litter depth		(inches) .3
Sound residue 3.1-inch diameter and larger	Jeffrey pine	(percent) 64
	white fir	(percent) 27
		(percent)
Rotted residue 3.1-inch diameter and larger		(percent) 9

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 18	x	
Net volume	(M fbm/acre) 12	x	
Average stems/acre cut	10		x
Average d.b.h. of stems cut	(inches) 34		x
Stand age	(years) 300		x
Cutting prescription	Shelterwood	x	
Yarding method	Tractor	x	
Slash treatment	Tractor pile & burn	x	
Period since cut or treatment	(months) 22	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 0
Flame length	(feet) 0
Resistance to suppression	(chains/man-hour) 3.0

REMARKS

First entry in old-growth stand.



DATA SHEET Residue descriptive code 2-MC-4-RC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.4	27
0.26- 1.0	5.7	381
1.1 - 3.0	11.8	945
3.1 - 9.0	8.9	726
9.1 -20.0	2.7	216
20.1+	6.9	553
Total	36.4	2,848

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.5
Ground area covered by residue 1/4-inch diameter and larger		(percent) 91
Average duff and litter depth		(inches) 1.4
Sound residue 3.1-inch diameter and larger	Jeffrey pine	(percent) 75
	white fir	(percent) 21
	other	(percent) 4
Rotted residue 3.1-inch diameter and larger		(percent) 0

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 22	x	
Net volume	(M fbm/acre) 20	x	
Average stems/acre cut	54	x	
Average d.b.h. of stems cut	(inches) 24	x	
Stand age	(years) 250		x
Cutting prescription	Clearcut	x	
Yarding method	High-lead	x	
Slash treatment	None	x	
Period since cut or treatment	(months) 7	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 9
Flame length	(feet) 6
Resistance to suppression	(chains/man-hour) 1.1

REMARKS

First entry in old-growth stand.



DATA SHEET

Residue descriptive code 3-MC-4-RC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.7	47
0.26- 1.0	9.6	641
1.1 - 3.0	21.6	1,731
3.1 - 9.0	13.7	1,152
9.1 -20.0	52.4	4,340
20.1+	27.9	2,351
Total	125.9	10,262

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.9
Ground area covered by residue 1/4-inch diameter and larger		(percent) 87
Average duff and litter depth		(inches) 2.1
Sound residue 3.1-inch diameter and larger	white fir	(percent) 38
	sugar pine	(percent) 24
	other	(percent) 38
Rotted residue 3.1-inch diameter and larger		(percent) 0

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 11.4	x	
Net volume	(M fbm/acre) 10.1	x	
Average stems/acre cut	12	x	
Average d.b.h. of stems cut	(inches) 23	x	
Stand age	(years) 150	x	
Cutting prescription	Clearcut	x	
Yarding method	Tractor	x	
Slash treatment	None	x	
Period since cut or treatment	(months) 6	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 12
Flame length	(feet) 8
Resistance to suppression	(chains/man-hour) 0.4

REMARKS

Old slash from partial cut prior to this clearcut entry was in evidence.

MIXED CONIFER

SIZE CLASS 4

PARTIAL CUT

A SERIES OF 8 LEVELS

REMINDER TO USERS:

1. The marker in these photos is 1 foot square, and the pole is painted in contrasting colors at 1-foot intervals to provide perspective.

2. Stumps are not included in residue quantities.

3. Rotted residue is that which would come apart or splinter when kicked.



DATA SHEET

Residue descriptive code 1-MC-4-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.2	13
0.26- 1.0	2.0	134
1.1 - 3.0	3.8	304
3.1 - 9.0	.5	42
9.1 -20.0	0	0
20.1+	0	0
Total	6.5	493

OTHER MEASUREMENTS		
Average residue depth	(feet)	0.01
Ground area covered by residue 1/4-inch diameter and larger	(percent)	89
Average duff and litter depth	(inches)	.1
Sound residue 3.1-inch diameter and larger white fir	(percent)	60
incense-cedar	(percent)	40
	(percent)	
Rotted residue 3.1-inch diameter and larger	(percent)	0

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 4.6	x	
Net volume	(M fbm/acre) 4.6	x	
Average stems/acre cut	15	x	
Average d.b.h. of stems cut	(inches) 22	x	
Stand age	(years) 150		x
Cutting prescription	Tree selection	x	
Yarding method	Tractor	x	
Slash treatment	Machine pile & burn		x
Period since cut or treatment	(months) 8		x

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY		
Spread rate	(chains/hour)	3
Flame length	(feet)	2
Resistance to suppression	(chains/man-hour)	6.0

REMARKS



DATA SHEET

Residue descriptive code 2-MC-4-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	1.0	67
0.26- 1.0	4.1	274
1.1 - 3.0	8.0	641
3.1 - 9.0	9.6	751
9.1 -20.0	3.9	284
20.1+	0	0
Total	26.6	2,017

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.4
Ground area covered by residue 1/4-inch diameter and larger		(percent) 100
Average duff and litter depth		(inches) 1.8
Sound residue 3.1-inch diameter and larger	Douglas-fir	(percent) 43
	incense-cedar	(percent) 34
	other	(percent) 19
Rotted residue 3.1-inch diameter and larger		(percent) 4

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 5.8	x	
Net volume	(M fbm/acre) 5.3	x	
Average stems/acre cut	23	x	
Average d.b.h. of stems cut	(inches) 20	x	
Stand age	(years) 150	x	
Cutting prescription	Overstory removal	x	
Yarding method	Rubber tire skidder	x	
Slash treatment	Machine treat[17]	x	
Period since cut or treatment	(months) 3	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 3
Flame length	(feet) 3
Resistance to suppression	(chains/man-hour) 1.0

REMARKS

Treated with Hydro-ax machine.



DATA SHEET Residue descriptive code 3-MC-4-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0	0
0.26- 1.0	.4	27
1.1 - 3.0	3.1	248
3.1 - 9.0	8.9	766
9.1 -20.0	12.2	1,140
20.1+	4.0	427
Total	28.6	2,608

OTHER MEASUREMENTS			
Average residue depth		(feet)	0.2
Ground area covered by residue 1/4-inch diameter and larger		(percent)	36
Average duff and litter depth		(inches)	.6
Sound residue 3.1-inch diameter and larger	incense-cedar	(percent)	25
	sugar pine	(percent)	16
	other	(percent)	19
Rotted residue 3.1-inch diameter and larger		(percent)	40

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 35	x	
Net volume	(M fbm/acre) 33.5	x	
Average stems/acre cut	32	x	
Average d.b.h. of stems cut	(inches) 22	x	
Stand age	(years) 250		x
Cutting prescription	Group selection	x	
Yarding method	skyline	x	
Slash treatment	YUM[1] & underburn	x	
Period since cut or treatment	(months) .1	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY		
Spread rate	(chains/hour)	0
Flame length	(feet)	0
Resistance to suppression	(chains/man-hour)	2.4

REMARKS
First entry in old-growth stand.

[1] Merchantable; unmerchantable material (YUM) down to 8-inch diameter, small end, and 10-foot length.



DATA SHEET Residue descriptive code 4-MC-4-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.8	53
0.26- 1.0	4.0	267
1.1 - 3.0	6.2	497
3.1 - 9.0	14.7	1,071
9.1 -20.0	8.9	724
20.1+	3.6	296
Total	38.2	2,908

OTHER MEASUREMENTS		
Average residue depth		(feet) 1.1
Ground area covered by residue 1/4-inch diameter and larger		(percent) 91
Average duff and litter depth		(inches) 1.7
Sound residue 3.1-inch diameter and larger	white fir	(percent) 38
	Douglas-fir	(percent) 18
		(percent) 36
Rotted residue 3.1-inch diameter and larger		(percent) 8

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 24	x	
Net volume	(M fbm/acre) 22	x	
Average stems/acre cut	15	x	
Average d.b.h. of stems cut	(inches) 24	x	
Stand age	(years) 200+	x	
Cutting prescription	Overstory removal	x	
Yarding method	Tractor	x	
Slash treatment	None	x	
Period since cut or treatment	(months) 12	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 7
Flame length	(feet) 4
Resistance to suppression	(chains/man-hour) 1.2

REMARKS

Much old, untreated slash on ground from prior sales.



DATA SHEET

Residue descriptive code 5-MC-4-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.5	33
0.26- 1.0	5.3	354
1.1 - 3.0	12.0	962
3.1 - 9.0	12.9	1,113
9.1 -20.0	10.8	915
20.1+	0	0
Total	41.5	3,377

OTHER MEASUREMENTS		
Average residue depth	(feet)	0.1
Ground area covered by residue 1/4-inch diameter and larger	(percent)	69
Average duff and litter depth	(inches)	.3
Sound residue 3.1-inch diameter and larger incense-cedar	(percent)	85
ponderosa pine	(percent)	15
	(percent)	
Rotted residue 3.1-inch diameter and larger	(percent)	0

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 5.8	x	
Net volume	(M fbm/acre) 5.8	x	
Average stems/acre cut	7	x	
Average d.b.h. of stems cut	(inches) 26	x	
Stand age	(years) 100		x
Cutting prescription	Tree selection	x	
Yarding method	Tractor	x	
Slash treatment	None	x	
Period since cut or treatment	(months) 8		x

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY		
Spread rate	(chains/hour)	9
Flame length	(feet)	6
Resistance to suppression	(chains/man-hour)	0.9

REMARKS





DATA SHEET Residue descriptive code 6-MC-4-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	1.6	107
0.26- 1.0	8.7	581
1.1 - 3.0	6.1	489
3.1 - 9.0	20.5	1,772
9.1 -20.0	6.9	632
20.1+	0	0
Total	43.8	3,581

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.4
Ground area covered by residue 1/4-inch diameter and larger		(percent) 97
Average duff and litter depth		(inches) .4
Sound residue 3.1-inch diameter and larger	white fir	(percent) 54
	incense-cedar	(percent) 24
		(percent)
Rotted residue 3.1-inch diameter and larger		(percent) 22

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 23	x	
Net volume	(M fbm/acre) 20.5	x	
Average stems/acre cut	34	x	
Average d.b.h. of stems cut	(inches) 26	x	
Stand age	(years) 100		x
Logging prescription	Tree selection	x	
Yarding method	Tractor	x	
Slash treatment	None	x	
Period since cut or treatment	(months) 36	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 10
Flame length	(feet) 6
Resistance to suppression	(chains/man-hour) 0.7

REMARKS

Some old, untreated slash on ground from cutting prior to the recent sale.



DATA SHEET

Residue descriptive code 7-MC-4-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.6	40
0.26- 1.0	6.7	447
1.1 - 3.0	10.8	865
3.1 - 9.0	3.7	254
9.1 -20.0	8.0	693
20.1+	21.2	1,774
Total	51.0	4,073

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.3
Ground area covered by residue 1/4-inch diameter and larger		(percent) 67
Average duff and litter depth		(inches) 2.4
Sound residue 3.1-inch diameter and larger	incense-cedar	(percent) 52
	white fir	(percent) 45
	other	(percent) 3
Rotted residue 3.1-inch diameter and larger		(percent) 0

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 27	____	x
Net volume	(M fbm/acre) 23	____	x
Average stems/acre cut	30	____	x
Average d.b.h. of stems cut	(inches) 28	____	x
Stand age	(years) 250	____	x
Cutting prescription	Tree selection	____	x
Yarding method	Tractor	____	x
Slash treatment	None	____	x
Period since cut or treatment	(months) 12	____	x

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 9
Flame length	(feet) 6
Resistance to suppression	(chains/man-hour) 0.6

REMARKS



DATA SHEET

Residue descriptive code 8-MC-4-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	1.0	67
0.26- 1.0	5.9	394
1.1 - 3.0	7.9	633
3.1 - 9.0	22.9	1,741
9.1 -20.0	7.3	647
20.1+	16.5	1,102
Total	61.5	4,584

OTHER MEASUREMENTS			
Average residue depth		(feet)	1.0
Ground area covered by residue 1/4-inch diameter and larger		(percent)	95
Average duff and litter depth		(inches)	1.0
Sound residue 3.1-inch diameter and larger	Douglas-fir	(percent)	68
	ponderosa pine	(percent)	4
	other	(percent)	1
Rotted residue 3.1-inch diameter and larger		(percent)	27

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 5.5	____	x
Net volume	(M fbm/acre) 4.8	____	x
Average stems/acre cut	24	x	____
Average d.b.h. of stems cut	(inches) 17	x	____
Stand age	(years) 80	x	____
Cutting prescription	Tree selection	x	____
Yarding method	Tractor	x	____
Slash treatment	None	x	____
Period since cut or treatment	(months) 12	x	____

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY		
Spread rate	(chains/hour)	9
Flame length	(feet)	5
Resistance to suppression	(chains/man-hour)	0.7

REMARKS

Some old, large residue from early cutting existed on this site prior to recent cutting.

MIXED CONIFER

SIZE CLASS 3

PARTIAL CUT

A SERIES OF 8 LEVELS

REMINDER TO USERS:

1. The marker in these photos is 1 foot square, and the pole is painted in contrasting colors at 1-foot intervals to provide perspective.

2. Stumps are not included in residue quantities.

3. Rotted residue is that which would come apart or splinter when kicked.



DATA SHEET

Residue descriptive code 1-MC-3-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.2	13
0.26- 1.0	1.9	127
1.1 - 3.0	.8	64
3.1 - 9.0	.4	35
9.1 -20.0	1.1	95
20.1+	0	0
Total	4.4	334

OTHER MEASUREMENTS		
Average residue depth	(feet)	0.1
Ground area covered by residue 1/4-inch diameter and larger	(percent)	88
Average duff and litter depth	(inches)	.8
Sound residue 3.1-inch diameter and larger incense-cedar	(percent)	100
	(percent)	
	(percent)	
Rotted residue 3.1-inch diameter and larger	(percent)	0

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 3.9		x
Net volume	(M fbm/acre) 3.8		x
Average stems/acre cut	30		x
Average d.b.h. of stems cut	(inches) 15		x
Stand age	(years) 80		x
Cutting prescription	Tree selection		x
Yarding method	Tractor		x
Slash treatment	Hand piled & burned		x
Period since cut or treatment	(months) 30		x

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY		
Spread rate	(chains/hour)	4
Flame length	(feet)	2
Resistance to suppression	(chains/man-hour)	6.0

REMARKS

General marking rule on this sale was to cut all stems over 10-inch d.b.h.



DATA SHEET

Residue descriptive code 2-MC-3-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.2	13
0.26- 1.0	2.8	187
1.1 - 3.0	3.1	248
3.1 - 9.0	4.9	413
9.1 -20.0	1.2	96
20.1+	0	0
Total	12.2	957

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.4
Ground area covered by residue 1/4-inch diameter and larger		(percent) 85
Average duff and litter depth		(inches) 1.1
Sound residue 3.1-inch diameter and larger	ponderosa pine	(percent) 43
	Jeffrey pine	(percent) 39
	incense-cedar	(percent) 3
Rotted residue 3.1-inch diameter and larger		(percent) 15

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 6.5		x
Net volume	(M fbm/acre) 6.3		x
Average stems/acre cut	50		x
Average d.b.h. of stems cut	(inches) 15		x
Stand age	(years) 80		x
Cutting prescription	Tree selection		x
Yarding method	Tractor		x
Slash treatment	None		x
Period since cut or treatment	(months) 24	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 12
Flame length	(feet) 6
Resistance to suppression	(chains/man-hour) 2.0

REMARKS

General marking rule on this sale was to cut all stems over 10-inch d.b.h.



DATA SHEET

Residue descriptive code 3-MC-3-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.4	27
0.26- 1.0	2.6	174
1.1 - 3.0	5.1	409
3.1 - 9.0	6.9	417
9.1 -20.0	0	0
20.1+	0	0
Total	15.0	1,027

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.2
Ground area covered by residue 1/4-inch diameter and larger		(percent) 69
Average duff and litter depth		(inches) .8
Sound residue 3.1-inch diameter and larger	black oak	(percent) 65
	incense-cedar	(percent) 25
	ponderosa pine	(percent) 10
Rotted residue 3.1-inch diameter and larger		(percent) 0

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 6.7		x
Net volume	(M fbm/acre) 6.5	x	
Average stems/acre cut	19	x	
Average d.b.h. of stems cut	(inches) 20	x	
Stand age	(years) 90	x	
Cutting prescription	Tree selection	x	
Yarding method	Tractor	x	
Slash treatment	Lop & scatter;spot burn	x	
Period since cut or treatment	(months) 10	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 5
Flame length	(feet) 3
Resistance to suppression	(chains/man-hour) 2.4

REMARKS



DATA SHEET

Residue descriptive code 4-MC-3-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.5	33
0.26- 1.0	4.4	294
1.1 - 3.0	4.0	321
3.1 - 9.0	6.1	498
9.1 -20.0	1.4	120
20.1+	0	0
Total	16.4	1,266

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.3
Ground area covered by residue 1/4-inch diameter and larger		(percent) 91
Average duff and litter depth		(inches) 1.2
Sound residue 3.1-inch diameter and larger	ponderosa pine	(percent) 67
	Douglas-fir	(percent) 12
		(percent)
Rotted residue 3.1-inch diameter and larger		(percent) 21

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 12.5	x	
Net volume	(M fbm/acre) 12.5	x	
Average stems/acre cut	28	x	
Average d.b.h. of stems cut	(inches) 19	x	
Stand age	(years) 60	x	
Cutting prescription	Tree selection	x	
Yarding method	Tractor	x	
Slash treatment	Lop & scatter	x	
Period since cut or treatment	(months) 12	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 7
Flame length	(feet) 4
Resistance to suppression	(chains/man-hour) 2.0

REMARKS



DATA SHEET

Residue descriptive code 5-MC-3-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.3	20
0.26- 1.0	2.6	174
1.1 - 3.0	4.4	353
3.1 - 9.0	7.0	566
9.1 -20.0	5.6	449
20.1+	0	0
Total	19.9	1,562

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.6
Ground area covered by residue 1/4-inch diameter and larger		(percent) 87
Average duff and litter depth		(inches) 1.1
Sound residue 3.1-inch diameter and larger	Jeffrey pine	(percent) 89
	white fir	(percent) 7
	incense-cedar	(percent) 4
Rotted residue 3.1-inch diameter and larger		(percent) 0

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 8.6		x
Net volume	(M fbm/acre) 8.4		x
Average stems/acre cut	60		x
Average d.b.h. of stems cut	(inches) 15		x
Stand age	(years) 80		x
Cutting prescription	Tree selection		x
Yarding method	Tractor		x
Slash treatment	None		x
Period since cut or treatment	(months) 30	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 13
Flame length	(feet) 6
Resistance to suppression	(chains/man-hour) 1.7

REMARKS

General marking rule on this sale was to cut all stems over 10-inch d.b.h.



DATA SHEET

Residue descriptive code 6-MC-3-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.1	7
0.26- 1.0	2.3	154
1.1 - 3.0	3.0	240
3.1 - 9.0	10.9	978
9.1 -20.0	2.0	192
20.1+	2.1	224
Total	20.4	1,795

OTHER MEASUREMENTS		
Average residue depth	(feet)	0.6
Ground area covered by residue 1/4-inch diameter and larger	(percent)	100
Average duff and litter depth	(inches)	3.4
Sound residue 3.1-inch diameter and larger ponderosa pine	(percent)	45
	(percent)	
	(percent)	
Rotted residue 3.1-inch diameter and larger	(percent)	55

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) *		
Net volume	(M fbm/acre) *		
Average stems/acre cut	100		x
Average d.b.h. of stems cut	(inches) 6		x
Stand age	(years) 90		x
Cutting prescription	Understory removal[1/]		x
Yarding method			x
Slash treatment	Broadcast burn		x
Period since cut or treatment	(months) 60		x

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY		
Spread rate	(chains/hour)	5
Flame length	(feet)	3
Resistance to suppression	(chains/man-hour)	1.3

REMARKS

Understory removed by precommercial thinning.

[1/] See remarks.



DATA SHEET Residue descriptive code 7-MC-3-PC

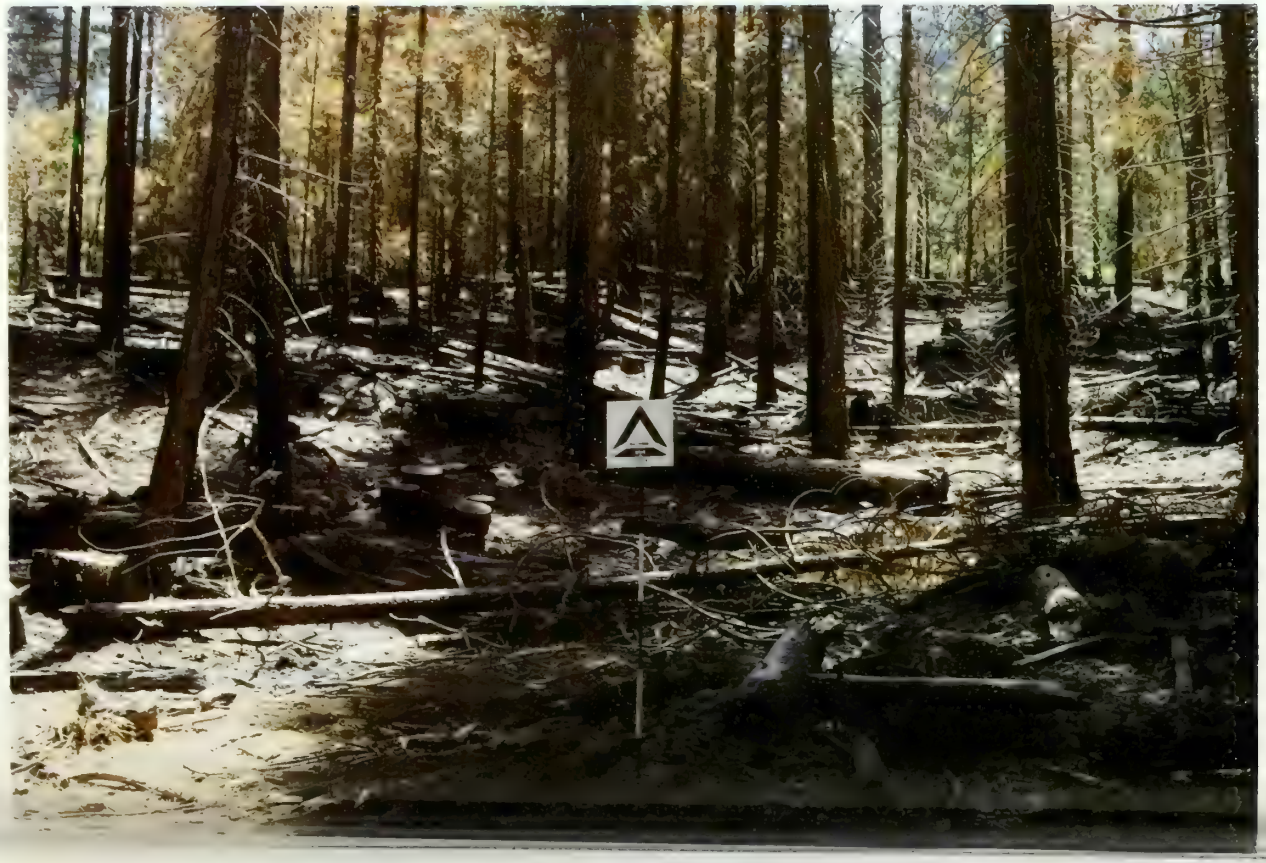
LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.8	53
0.26- 1.0	7.2	481
1.1 - 3.0	7.5	601
3.1 - 9.0	6.9	491
9.1 -20.0	3.2	342
20.1+	0	0
Total	25.6	1,968

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.6
Ground area covered by residue 1/4-inch diameter and larger		(percent) 83
Average duff and litter depth		(inches) .8
Sound residue 3.1-inch diameter and larger	ponderosa pine	(percent) 36
	black oak	(percent) 17
		(percent)
Rotted residue 3.1-inch diameter and larger		(percent) 47

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 12.5	x	
Net volume	(M fbm/acre) 12.5	x	
Average stems/acre cut	28	x	
Average d.b.h. of stems cut	(inches) 19	x	
Stand age	(years) 60	x	
Cutting prescription	Tree selection	x	
Yarding method	Tractor	x	
Slash treatment	None	x	
Period since cut or treatment	(months) 12	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 9
Flame length	(feet) 6
Resistance to suppression	0.9 (chains/man-hour)

REMARKS



DATA SHEET Residue descriptive code 8-MC-3-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.2	13
0.26- 1.0	1.8	120
1.1 - 3.0	3.7	296
3.1 - 9.0	13.3	1,127
9.1 -20.0	20.7	1,761
20.1+	13.6	1,202
Total	53.3	4,519

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.3
Ground area covered by residue 1/4-inch diameter and larger		(percent) 57
Average duff and litter depth		(inches) .4
Sound residue 3.1-inch diameter and larger	ponderosa pine	(percent) 58
	incense-cedar	(percent) 16
	white fir	(percent) 5
Rotted residue 3.1-inch diameter and larger		(percent) 21

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 7.5		x
Net volume	(M fbm/acre) 6.5	x	
Average stems/acre cut	19	x	
Average d.b.h. of stems cut	(inches) 20	x	
Stand age	(years) 90	x	
Cutting prescription	Tree selection	x	
Yarding method	Tractor	x	
Slash treatment	Broadcast burn	x	
Period since cut or treatment	(months) 2	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 0
Flame length	(feet) 0
Resistance to suppression	(chains/man-hour) 1.5

REMARKS

TRUE FIR

SIZE CLASS 4

REGENERATION CUT

A SERIES OF 6 LEVELS

REMINDERS TO USERS:

1. The marker in these photos is 1 foot square, and the pole is painted in contrasting colors at 1-foot intervals to provide perspective.

2. Stumps are not included in residue quantities.

3. Rotted residue is that which would come apart or splinter when kicked.



DATA SHEET Residue descriptive code 1-TF-4-RC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.2	13
0.26- 1.0	1.1	73
1.1 - 3.0	2.9	232
3.1 - 9.0	.4	34
9.1 -20.0	0	0
20.1+	0	0
Total	4.6	352

OTHER MEASUREMENTS		
Average residue depth	(feet)	0.1
Ground area covered by residue 1/4-inch diameter and larger	(percent)	68
Average duff and litter depth	(inches)	.2
Sound residue 3.1-inch diameter and larger red fir	(percent)	100
	(percent)	
	(percent)	
Rotted residue 3.1-inch diameter and larger	(percent)	0

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 30		x
Net volume	(M fbm/acre) 28		x
Average stems/acre cut	32		x
Average d.b.h. of stems cut	(inches) 25	x	
Stand age	(years) 150	x	
Cutting prescription	Shelterwood	x	
Yarding method	Tractor	x	
Slash treatment	Broadcast burn	x	
Period since cut or treatment	(months) 24	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY		
Spread rate	(chains/hour)	0
Flame length	(feet)	0
Resistance to suppression	(chains/man-hour)	12

REMARKS



DATA SHEET Residue descriptive code 2-TF-4-RC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.3	20
0.26- 1.0	1.4	93
1.1 - 3.0	3.8	304
3.1 - 9.0	1.4	121
9.1 -20.0	0	0
20.1+	0	0
Total	6.9	538

OTHER MEASUREMENTS		
Average residue depth	(feet)	0.1
Ground area covered by residue 1/4-inch diameter and larger	(percent)	93
Average duff and litter depth	(inches)	.6
Sound residue 3.1-inch diameter and larger grand fir	(percent)	100
	(percent)	
	(percent)	
Rotted residue 3.1-inch diameter and larger	(percent)	0

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 14		x
Net volume	(M fbm/acre) 13		x
Average stems/acre cut	15		x
Average d.b.h. of stems cut	(inches) 25	x	
Stand age	(years) 150	x	
Cutting prescription	Shelterwood	x	
Yarding method	Tractor	x	
Slash treatment	Machine pile & burn	x	
Period since cut or treatment	(months) 24	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY		
Spread rate	(chains/hour)	0
Flame length	(feet)	0
Resistance to suppression	(chains/man-hour)	6.0

REMARKS

Complete history of this site not known, but it appeared that at least two entries had been made prior to the shelterwood cut.



DATA SHEET

Residue descriptive code 3-TF-4-RC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.3	20
0.26- 1.0	3.6	240
1.1 - 3.0	12.1	970
3.1 - 9.0	6.4	560
9.1 -20.0	4.1	357
20.1+	0	0
Total	26.5	2,147

OTHER MEASUREMENTS		
Average residue depth	(feet)	0.4
Ground area covered by residue 1/4-inch diameter and larger	(percent)	100
Average duff and litter depth	(inches)	.7
Sound residue 3.1-inch diameter and larger red fir	(percent)	84
	(percent)	
	(percent)	
Rotted residue 3.1-inch diameter and larger	(percent)	16

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 40		x
Net volume	(M fbm/acre) 38		x
Average stems/acre cut	36		x
Average d.b.h. of stems cut	(inches) 25	x	
Stand age	(years) 150	x	
Cutting prescription	Shelterwood	x	
Yarding method	Tractor	x	
Slash treatment	YUM[1/] & machine treat[2/]	x	
Period since cut or treatment	(months)	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY		
Spread rate	(chains/hour)	2
Flame length	(feet)	3
Resistance to suppression	(chains/man-hour)	1.3

REMARKS

Treated with Trackmac machine.

[1/] Required yarding unmerchantable material (YUM) down to 10-inch diameter, small end, and 10-foot length.

[2/] See remarks.



DATA SHEET

Residue descriptive code 4-TF-4-RC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.9	60
0.26- 1.0	5.3	354
1.1 - 3.0	4.6	369
3.1 - 9.0	15.8	1,338
9.1 -20.0	2.1	195
20.1+	0	0
Total	28.7	2,316

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.3
Ground area covered by residue 1/4-inch diameter and larger		(percent) 88
Average duff and litter depth		(inches) .4
Sound residue 3.1-inch diameter and larger	white fir	(percent) 83
		(percent)
		(percent)
Rotted residue 3.1-inch diameter and larger		(percent) 17

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 36		x
Net volume	(M fbm/acre) 33		x
Average stems/acre cut	34	x	
Average d.b.h. of stems cut	(inches) 26	x	
Stand age	(years) 200		x
Cutting prescription	Tree selection	x	
Yarding method	Tractor	x	
Slash treatment	Burned concentrations		x
Period since cut or treatment	(months) 18		x

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 5
Flame length	(feet) 4
Resistance to suppression	(chains/man-hour) 1.1

REMARKS



DATA SHEET

Residue descriptive code 5-TF-4-RC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.2	13
0.26- 1.0	2.0	134
1.1 - 3.0	4.8	385
3.1 - 9.0	11.0	945
9.1 -20.0	10.4	911
20.1+	3.1	261
Total	31.5	2,649

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.2
Ground area covered by residue 1/4-inch diameter and larger		(percent) 95
Average duff and litter depth		(inches) .7
Sound residue 3.1-inch diameter and larger	red fir	(percent) 86
	western white pine	(percent) 2
		(percent)
Rotted residue 3.1-inch diameter and larger		(percent) 12

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 12		x
Net volume	(M fbm/acre) 11		x
Average stems/acre cut	10		x
Average d.b.h. of stems cut	(inches) 25	x	
Stand age	(years) 200		x
Cutting prescription	Shelterwood	x	
Yarding method	Tractor	x	
Slash treatment	Lop to 25-inch height	x	
Period since cut or treatment	(months) 24	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 5
Flame length	(feet) 3
Resistance to suppression	(chains/man-hour) 2.0

REMARKS

Entry prior to this cut had left much large, untreated residue.



DATA SHEET

Residue descriptive code 6-TF-4-RC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	1.6	107
0.26- 1.0	6.3	421
1.1 - 3.0	6.2	497
3.1 - 9.0	16.2	1,372
9.1 -20.0	28.1	2,499
20.1+	25.6	2,604
Total	84.0	7,500

OTHER MEASUREMENTS		
Average residue depth	(feet)	0.7
Ground area covered by residue 1/4-inch diameter and larger	(percent)	92
Average duff and litter depth	(inches)	.2
Sound residue 3.1-inch diameter and larger white fir	(percent)	48
incense-cedar	(percent)	4
	(percent)	
Rotted residue 3.1-inch diameter and larger	(percent)	48

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 40		x
Net volume	(M fbm/acre) 35		x
Average stems/acre cut	43	x	
Average d.b.h. of stems cut	(inches) 24	x	
Stand age	(years) 150		x
Cutting prescription	Clearcut	x	
Yarding method	Tractor	x	
Slash treatment	None	x	
Period since cut or treatment	(months) 15	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY		
Spread rate	(chains/hour)	8
Flame length	(feet)	5
Resistance to suppression	(chains/man-hour)	0.7

REMARKS

TRUE FIR

SIZE CLASS 4

PARTIAL CUT

A SERIES OF 5 LEVELS

REMINDERS TO USERS:

1. The marker in these photos is 1 foot square, and theppole is painted in contrasting colors at 1-foot intervals to provide perspective.

2. Stumps are not included in residue quantities.

3. Rotted residue is that which would come apart or splinter when kicked.



DATA SHEET

Residue descriptive code 1-TF-4-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.5	33
0.26- 1.0	2.2	147
1.1 - 3.0	6.3	505
3.1 - 9.0	7.3	627
9.1 -20.0	1.3	110
20.1+	0	0
Total	17.6	1,422

OTHER MEASUREMENTS		
Average residue depth	(feet)	0.4
Ground area covered by residue 1/4-inch diameter and larger	(percent)	95
Average duff and litter depth	(inches)	.5
Sound residue 3.1-inch diameter and larger red fir	(percent)	93
	(percent)	
	(percent)	
Rotted residue 3.1-inch diameter and larger	(percent)	7

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 30		x
Net volume	(M fbm/acre) 29		x
Average stems/acre cut	32		x
Average d.b.h. of stems cut	(inches) 25	x	
Stand age	(years) 150		x
Cutting prescription	Group selection		x
Yarding method	Tractor	x	
Slash treatment	Lop to 25-inch height	x	
Period since cut or treatment	(months) 24	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY		
Spread rate	(chains/hour)	3
Flame length	(feet)	2
Resistance to suppression	(chains/man-hour)	3.0

REMARKS



DATA SHEET

Residue descriptive code 2-TF-4-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.3	20
0.26- 1.0	2.1	140
1.1 - 3.0	3.5	280
3.1 - 9.0	8.9	765
9.1 -20.0	3.9	403
20.1+	6.0	481
Total	24.7	2,089

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.3
Ground area covered by residue 1/4-inch diameter and larger		(percent) 97
Average duff and litter depth		(inches) 2.0
Sound residue 3.1-inch diameter and larger	white fir	(percent) 27
	ponderosa pine	(percent) 33
	other	(percent) 12
Rotted residue 3.1-inch diameter and larger		(percent) 28

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 4.5		x
Net volume	(M fbm/acre) 4.0		x
Average stems/acre cut	2	x	
Average d.b.h. of stems cut	(inches) 44	x	
Stand age	(years) 250	x	
Cutting prescription	Tree selection	x	
Yarding method	Tractor	x	
Slash treatment	YUM[1/]		x
Period since cut or treatment	(months) 14	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 5
Flame length	(feet) 3
Resistance to suppression	(chains/man-hour) 1.7

REMARKS

[1/] Required yarding unmerchantable material (YUM) down to 8-inch diameter, small end, and 10-foot length.



DATA SHEET

Residue descriptive code 3-TF-4-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	1.2	80
0.26- 1.0	4.1	274
1.1 - 3.0	6.6	529
3.1 - 9.0	10.6	909
9.1 -20.0	12.7	1,113
20.1+	3.8	321
Total	39.0	3,226

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.4
Ground area covered by residue 1/4-inch diameter and larger		(percent) 100
Average duff and litter depth		(inches) 1.8
Sound residue 3.1-inch diameter and larger	red fir	(percent) 57
	white fir	(percent) 26
	ponderosa pine	(percent) 2
Rotted residue 3.1-inch diameter and larger		(percent) 15

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 22		x
Net volume	(M fbm/acre) 18		x
Average stems/acre cut	11	x	
Average d.b.h. of stems cut	(inches) 30	x	
Stand age	(years) 250	x	
Cutting prescription	Group selection	x	
Yarding method	Tractor	x	
Slash treatment	Lop & scatter	x	
Period since cut or treatment	(months) 48	x	

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 7
Flame length	(feet) 4
Resistance to suppression	(chains/man-hour) 1.5

REMARKS



DATA SHEET

Residue descriptive code 4-TF-4-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	1.3	87
0.26- 1.0	5.8	387
1.1 - 3.0	7.8	625
3.1 - 9.0	19.1	1,586
9.1 -20.0	8.6	710
20.1+	6.4	526
Total	49.0	3,921

OTHER MEASUREMENTS		
Average residue depth		(feet) 0.6
Ground area covered by residue 1/4-inch diameter and larger		(percent) 99
Average duff and litter depth		(inches) 3.3
Sound residue 3.1-inch diameter and larger	white fir	(percent) 93
	incense-cedar	(percent) 3
	sugar pine	(percent) 2
Rotted residue 3.1-inch diameter and larger		(percent) 2

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 8.0	____	x
Net volume	(M fbm/acre) 7.5	____	x
Average stems/acre cut	30	____	x
Average d.b.h. of stems cut	(inches) 18	____	x
Stand age	(years) 120	____	x
Cutting prescription	Tree selection	____	x
Yarding method	Tractor	____	x
Slash treatment	None	____	x
Period since cut or treatment	(months) 30	____	x

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY	
Spread rate	(chains/hour) 8
Flame length	(feet) 5
Resistance to suppression	(chains/man-hour) 0.7

REMARKS



DATA SHEET Residue descriptive code 5-TF-4-PC

LOADING		
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)
0.0 - 0.25	0.5	33
0.26- 1.0	4.7	314
1.1 - 3.0	6.2	497
3.1 - 9.0	20.0	1,769
9.1 -20.0	45.0	3,767
20.1+	29.9	2,817
Total	106.3	9,197

OTHER MEASUREMENTS		
Average residue depth	(feet)	0.6
Ground area covered by residue 1/4-inch diameter and larger	(percent)	92
Average duff and litter depth	(inches)	5.0
Sound residue 3.1-inch diameter and larger white fir	(percent)	71
	(percent)	
	(percent)	
Rotted residue 3.1-inch diameter and larger	(percent)	29

HARVEST INFORMATION		HARVEST INFORMATION SOURCE	
		Sale records	Onsite estimation
Gross volume	(M fbm/acre) 1/		
Net volume	(M fbm/acre) 1/		
Average stems/acre cut	40		x
Average d.b.h. of stems cut	(inches) 20		x
Stand age	(years) 300		x
Cutting prescription	Sanitation cut		x
Yarding method	None		x
Slash treatment	None		x
Period since cut or treatment	(months) 96		x

1/ See remarks.

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY		
Spread rate	(chains/hour)	7
Flame length	(feet)	5
Resistance to suppression	(chains/man-hour)	0.5

REMARKS

No volume removed from cutting; trees were felled to remove diseased trees from stand.

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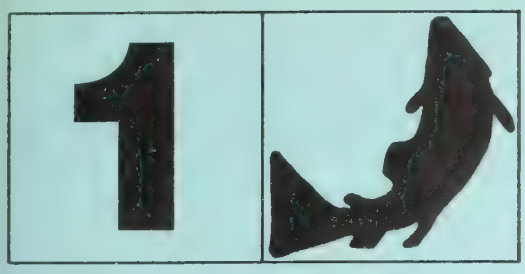
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General Technical Report PNW-96
October 1979

Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America

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HABITAT REQUIREMENTS OF ANADROMOUS SALMONIDS

D.W. REISER and T.C. BJORNN



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U.S. Department of Agriculture Forest Service
Pacific Northwest Forest and Range Experiment Station

ABSTRACT

Habitat requirements of anadromous and some resident salmonid fishes have been described for various life stages, including upstream migration of adults, spawning, incubation, and juvenile rearing.

Factors important in the migration of adults are water temperature, minimum water depth, maximum water velocity, turbidity, dissolved oxygen, and barriers.

Habitat requirements for successful spawning are suitable water temperature, water depth, water velocity, and substrate composition. Cover--riparian vegetation, undercut banks, and so on--is needed to protect salmonids waiting to spawn and may influence the selection of spawning locations.

Incubation requirements incorporate both extra- and intragravel factors. Extragravel factors are: dissolved oxygen, temperature, velocity, discharge, and biochemical oxygen demand of the stream. Intragravel factors are dissolved oxygen, temperature, permeability, apparent velocity, and sediment composition.

Important habitat components for juvenile rearing are fish food production areas, water quality, cover, and space. Good fish food production areas are mostly riffles with water depths of 0.15-0.91 m, water velocities of 0.30-0.46 m/s, and substrates of coarse gravel and rubble (3.2-30.4 cm). Good water quality for rearing salmonids includes mean summer water temperatures of 10.0°-14.0°C, dissolved oxygen at more than 80-percent saturation, suspended sediment less than 25 mg/liter, and fine sediment content of riffles less than 20 percent. Adequate cover--in the form of riparian vegetation, undercut banks, aquatic vegetation, and rubble-boulder areas--is needed to protect juvenile fish from predation and adverse physical factors.

KEYWORDS: fish habitat, anadromous fish, salmonids, habitat needs.

USDA FOREST SERVICE
General Technical Report PNW-96

INFLUENCE OF FOREST AND RANGELAND MANAGEMENT ON ANADROMOUS FISH HABITAT IN THE WESTERN UNITED STATES AND CANADA

William R. Meehan, Technical Editor

1. Habitat Requirements of Anadromous Salmonids

D. W. REISER AND T. C. BJORNN

Idaho Cooperative Fishery Research Unit
University of Idaho, Moscow

1979

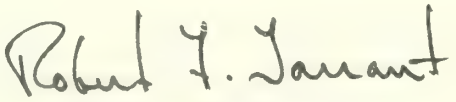
PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
Forest Service, U.S. Department of Agriculture Portland, Oregon

PREFACE

This, the first in a series of publications summarizing knowledge about the influences of forest and rangeland management on anadromous fish habitat in the Western United States, describes habitat requirements of anadromous salmonids--the valuable salmon and trout species that use both freshwater and marine environments. Requirements of these unique fish must be understood before we can explore the effects that natural events and human activities can have on their habitat, and on their ability to maintain productive populations with our increasing use of other forest and rangeland resources. Reports on the effects of natural watershed disturbances and various land use activities will follow.

We intend to present information in these publications that will provide managers and users of the forests and rangelands of the Western United States with the most complete information available for estimating consequences of various management alternatives.

In this series of papers, we will summarize published and unpublished reports and data as well as observations made by resource scientists and managers made during years of experience in the West. These compilations will be valuable in planning management of forest and rangeland resources, and to scientists in planning future research. The extensive lists of references will serve as a bibliography on forest and rangeland resources and their use for this part of the United States.



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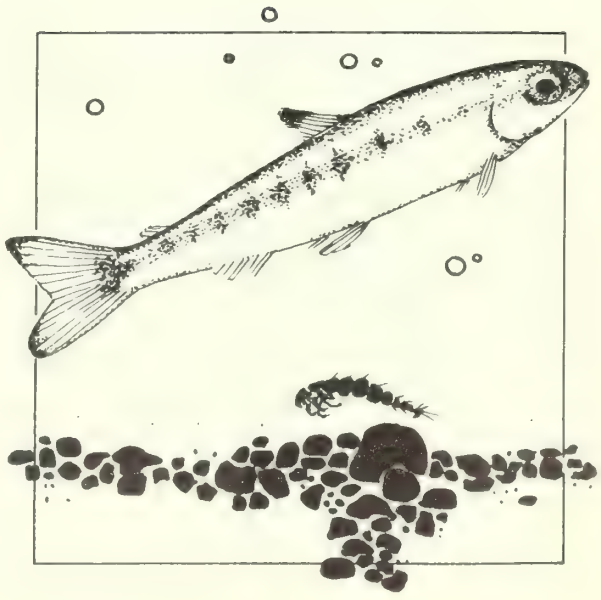
COMMON AND SCIENTIFIC NAMES OF TROUTS FAMILY SALMONIDAE[1/]

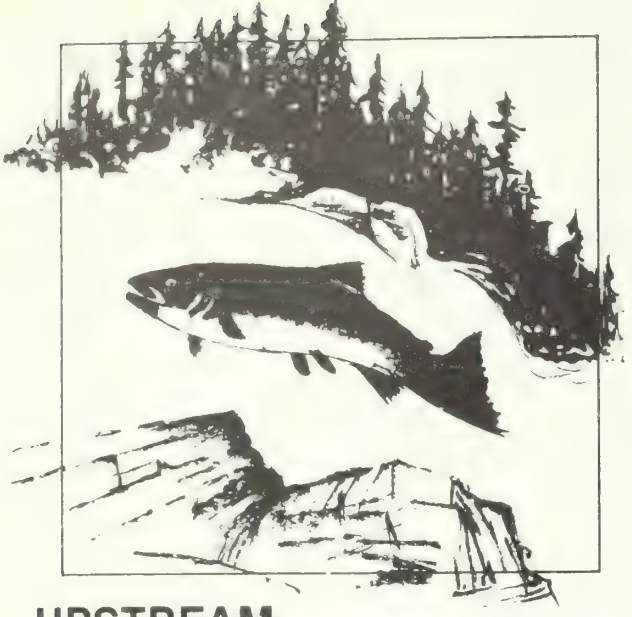
Common name	Scientific name
Pink salmon	*Oncorhynchus gorbuscha* (Walbaum)
Chum salmon	*Oncorhynchus keta* (Walbaum)
Coho salmon	*Oncorhynchus kisutch* (Walbaum)
Sockeye salmon (kokanee)	*Oncorhynchus nerka* (Walbaum)
Chinook salmon	*Oncorhynchus tshawytscha* (Walbaum)
Cutthroat trout	*Salmo clarki* Richardson
Rainbow (steelhead) trout	*Salmo gairdneri* Richardson
Atlantic salmon	*Salmo salar* Linnaeus
Brown trout	*Salmo trutta* Linnaeus
Arctic char	*Salvelinus alpinus* (Linnaeus)
Brook trout	*Salvelinus fontinalis* (Mitchill)
Dolly Varden	*Salvelinus malma* (Walbaum)
Lake trout	*Salvelinus namaycush* (Walbaum)

1/ From "A List of Common and Scientific Names of Fishes from the United States and Canada," American Fisheries Society Special Publication No. 6, Third Edition, 1970, 150 p.

INTRODUCTION

Habitat needs of anadromous salmonids (sea-run salmon and trout) in streams vary with the season of the year and the stage of their life cycle. Upstream migration of adults, spawning, incubation, juvenile rearing, and seaward migration of smolts are the major life stages for most anadromous salmonids. Insofar as possible, we have defined the range of habitat conditions for each life stage that will allow a population to thrive. Throughout this paper, we have included data for salmonids that are not anadromous because they illustrate the range of temperatures, velocities, and depths of waters preferred by salmonids, and these species are generally similar to the anadromous ones.





UPSTREAM MIGRATION OF ADULTS

Adult salmonids returning to their natal streams must arrive at the proper time and in good health if spawning is to be successful. Unfavorable discharges, temperatures, turbidity, and water quality could delay or prevent fish from completing their migration.

TEMPERATURE

Selected salmonid fishes have successfully migrated upstream in water temperatures ranging from 3° to 20°C (table 1). Temperatures above the upper limits have been known to stop the migration of fish.[1/]

Unusual stream temperatures can lead to disease outbreaks in migrating fish, altered timing of migration, and accelerated or retarded maturation. Most stocks of anadromous salmonids have evolved with the temperature patterns of their home streams, and significant abrupt deviations from the normal pattern could adversely affect their survival.

DISSOLVED OXYGEN

Reduced dissolved oxygen concentrations can adversely affect the swimming performance of migrating salmonids. Maximum sustained swimming speeds of juvenile and adult coho salmon at temperatures of 10°-20°C were adversely affected when oxygen was reduced from air-saturation levels (Davis et al. 1963). A sharp decrease in performance was noted at 6.5-7.0 mg/l for all temperatures tested. A similar relation has been observed by Graham (1949) for brook trout. Low dissolved oxygen may also elicit avoidance reactions as noted by Whitmore et al. (1960) and may cause migration to cease. The oxygen levels recommended for spawning fish (at least 80 percent of saturation, with temporary levels no lower than 5.0 mg/l) should provide the oxygen needs of migrating fish.

TURBIDITY

Migrating salmon will avoid or cease migration in waters with high silt loads (Cordone and Kelley 1961, Bell, see footnote 1). Bell cited a study in which salmonid fish would not move in streams where the sediment content was more than 4 000 mg/l. The turbid water resulted from a landslide. Turbid water will absorb more radiation than clear water and thus may indirectly result in a thermal barrier to migration.

BARRIERS

Waterfalls, debris jams, and excessive velocities may also impede migrating fish. Falls that are insurmountable

---

[1/] Unpublished report, "Fisheries handbook of engineering requirements and biological criteria. Useful factors in life history of most common species," by M. C. Bell. Submitted to Fish.-Eng. Res. Program, Corps of Eng., North Pac. Div., Portland, Oreg., 1973.

Table 1—Water temperature, depth, and velocity criteria for successful upstream migration of adult salmon and trout.

Species of fish	Temperature range[1/]	Minimum depth[2/]	Maximum velocity[2/]
	°C	Meters	Meters/second
Fall chinook salmon	10.6-19.4	0.24	2.44
Spring chinook salmon	3.3-13.3	.24	2.44
Summer chinook salmon	13.9-20.0	.24	2.44
Chum salmon	8.3-15.6	.18	2.44
Coho salmon	7.2-15.6	[3/].18	[3/]2.44
Pink salmon	7.2-15.6	[3/].18	[3/]2.13
Sockeye salmon	7.2-15.6	[3/].18	[3/]2.13
Steelhead trout	-	.18	2.44
Large trout	-	.18	2.44
Trout	-	.12	1.22

1/ From Bell (see text footnote 1).
2/ From Thompson (1972).
3/ Based on fish size.

at one time of the year may be passed by migrating fish at other times when flows have changed. Stuart (1962) determined in laboratory studies that ideal leaping conditions for fish are obtained with a ratio of a height of falls to depth of pool of 1:1.25. Figure 1 from Eiserman et al. (1975) depicts the leaping behavior of salmonids observed by Stuart. Given suitable conditions, salmon and steelhead can get past many obstacles that appear to be barriers. Both Jones (1959) and Stuart (1962) observed salmon jumping 2-3 m.

Debris jams, whether natural or caused by human activities, can prevent or delay upstream migration. Chapman (1962) cited a study in which a 75-percent decrease in spawning salmon in one stream was attributed to debris blockage. Debris barriers often form large pools and sediment traps that, if released, could adversely affect downstream spawning areas.

Some logs, leaves, dams, and so on, in streams are beneficial as cover for adult and juvenile fish. All debris jams should be evaluated carefully before they are removed.

Water velocities may exceed the swimming ability of migrating fish at channel constrictions during snow melt and storm runoff. Migration resumes when streamflows and associated velocities have decreased. The swimming abilities of fish are usually described in terms of cruising speed--the speed a fish can swim for an extended period of time (hours), usually ranging from 2 to 4 body lengths per second; sustained speed--the speed a fish can maintain for a period of several minutes, ranging from 4 to 7 body lengths per second; and darting or burst speed--the speed a fish can swim for a few seconds, ranging from 8 to 12 body lengths per second (Bell, see footnote 1; Watts 1974; table 2). According to Bell, cruising speed is used

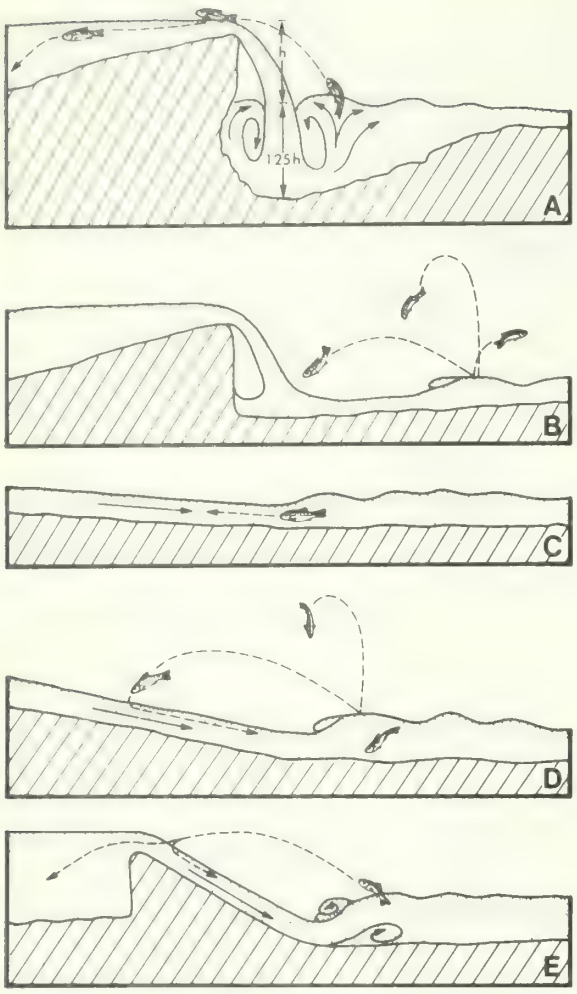


Figure 1—Leaping ability of salmonids (from Eiserman et al. 1975, diagrams drawn after Stuart 1962): A. Falling water enters the pool at nearly a 90° angle. A standing wave lies close to the waterfall where trout use its upward thrust in leaping. Plunge-pool depth is 1.25 times the distance (h) from the crest of the waterfall to the water level of the pool. B. The height of fall is the same, but pool depth is less. The standing wave is formed too far from the ledge to be useful to leaping trout. C. Flow down a gradual incline is slow enough to allow passage of ascending trout. D. Flow over a steeper incline is more than trout can swim against for much distance. Trout may even be repulsed in the standing wave at the foot of the incline. They sometimes leap futilely from the standing wave. E. A shorter barrier with outflow over steep incline may be ascended by trout with difficulty.

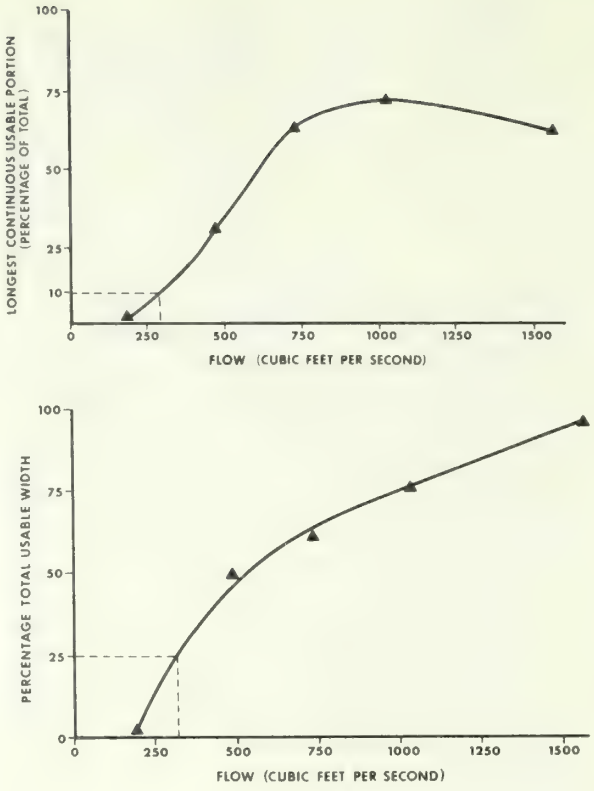


Figure 2—Salmonid passage flow determination (from Thompson 1972).

during migration, sustained speed for passage through difficult areas, and darting speed for escape and feeding. Velocities of 3-4 m/s approach the upper swimming ability of salmon and steelhead and may retard upstream migration.

STREAMFLOW

Migration can also be hampered by too little streamflow and resulting shallow water. Thompson (1972) established passage criteria for various salmonids based on minimum depth and maximum velocities (table 1). Stream discharges that will provide suitable depths and velocities for adult passage (figure 2) can be determined from the criteria and techniques described by Thompson (1972):

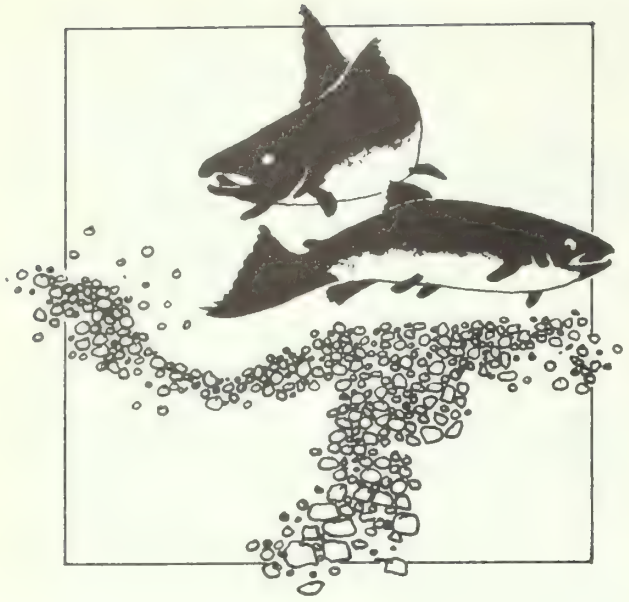
Table 2—Swimming abilities of average size adult salmonids[1/]

Species of fish	Cruising speed	Sustained speed	Darting speed
	Meters per second		
Chinook	0-1.04	1.04-3.29	3.29-6.83
Coho	0-1.04	1.04-3.23	3.23-6.55
Sockeye	0-0.98	.98-3.11	3.11-6.28
Steelhead	0-1.40	1.40-4.18	4.18-8.08
Trout	0-0.61	.61-1.95	1.95-4.11
Brown trout	0-0.67	.67-1.89	1.89-3.87

1/ From Bell (see text footnote 1).

> ...shallow bars most critical to passage of adult fish are located and a linear transect marked which follows the shallowest course from bank to bank. At each of several flows, the total width and longest continuous portion of the transect meeting minimum depth and maximum velocity criteria are measured. For each transect, the flow is selected that meets the criteria on at least 25 percent of the total transect width and a continuous portion equalling at least 10 percent of its total width.

The mean selected flow from all transects is recommended as the minimum flow for passage. Thompson (1972) noted that maximum acceptable passage flows could theoretically be defined, but we have not attempted to do so in this paper. Baxter (1961) reports that salmon need 30-50 percent of the average annual flow for passage through the lower and middle reaches in Scottish rivers and up to 70 percent for headwater streams.



SPAWNING

Cover, substrate composition, and water quality and quantity are important habitat elements for anadromous salmonids before and during spawning.

COVER

Cover for fish can be provided by overhanging vegetation, undercut banks, submerged vegetation, submerged objects--e.g. logs and rocks, floating debris, and water depth and turbulence (Giger 1973). Cover can protect the fish from disturbance and predation and also provide shade. Some anadromous fish--chinook salmon and steelhead, for example--enter freshwater streams months before they spawn, and cover is essential for fish waiting to spawn. Many spawning areas are relatively open segments on streams where fish are vulnerable to disturbance and predation during redd (nest) construction and spawning. Nearness of cover to spawning areas may be a factor in the actual selection of spawning sites by some species. Johnson et al. (1966) and Reiser and Wesche (1977) noted that many spawning brown trout selected areas adjacent to undercut banks and overhanging vegetation. Reiser and Wesche (1977) speculated that the early spawners and large dominant fish may select areas by cover. As these areas become occupied, the late spawners and small fish are forced to use relatively unprotected sites. Given a choice between two spawning areas, one with cover and one without, the fish would select the area with cover.

TEMPERATURE

Successful spawning of salmonids has occurred in water temperatures ranging from 2.2° to 20.0°C (table 3). A sudden drop in temperature may cause all spawning activity to cease, resulting in lowered nest building activity and reduced production (see footnote 1).

SUBSTRATE COMPOSITION

The suitability of a particular size gravel substrate depends mostly on fish size. Large fish can build redds in large substrate. To determine the substrate composition preferred by various salmonids, many investigators (Burner 1951, Cope 1957, Warner 1963, Orcutt et al. 1968, Hunter 1973, Reiser and Wesche 1977) collected gravel samples from active redds and graded them through a series of sieves. The substrate composition selected in artificial spawning channels reflects the judgment of those who determined the particle sizes best suited for selected species. In the Robertson Creek spawning channels, gravel ranging from 2 to 10 cm was used for pink, coho, and spring chinook salmon (Lucas 1959). In the Jones Creek spawning channel, gravel ranged from 0.6 to 3.8 cm (MacKinnon et al. 1961). The Tehama-Colusa

Table 3—Recommended temperatures for spawning and incubation of salmonid fishes[1/]

Species	Spawning temperature	Incubation temperature[2/]
	°C	
Fall chinook	5.6-13.9	5.0-14.4
Spring chinook	5.6-13.9	5.0-14.4
Summer chinook	5.6-13.9	5.0-14.4
Chum	7.2-12.8	4.4-13.3
Coho	4.4-9.4	4.4-13.3
Pink	7.2-12.8	4.4-13.3
Sockeye	10.6-12.2	4.4-13.3
Kokanee	5.0-12.8	---
Steelhead	3.9-9.4	---
Rainbow	2.2-20.0	---
Cutthroat	6.1-17.2	---
Brown	3/ 7.2-12.8	---

1/ From Bell (see text footnote 1).
2/ The higher and lower values are threshold temperatures at which mortality will increase if exceeded. Eggs will survive and develop normally at lower temperatures than indicated, provided initial development of the embryo has progressed to a stage that is tolerant of colder water.
3/ From Hunter (1973).

Table 4—Water depth, velocity, and substrate size criteria for anadromous and other salmonid spawning areas

Species of fish	Source	Depth	Velocity	Substrate size
		Meters	Cm/s	Centimeters
Fall chinook	Thompson (1972)	≥0.24	30-91	1/ 1.3-10.2
Spring chinook	Thompson (1972)	≥.24	30-91	1/ 1.3-10.2
Summer chinook	Reiser[2/]	≥.30	32-109	1/ 1.3-10.2
Chum	Smith (1973)	≥.18	46-101	1/ 1.3-10.2
Coho	Thompson (1972)	≥.18	30-91	3/ 1.3-10.2
Pink salmon	Collings[4/]	≥.15	21-101	1/ 1.3-10.2
Sockeye[5/]	---[3/]	≥.15	3/ 21-101	1/ 1.3-10.2
Kokanee	Smith (1973)	≥.06	15-73	-
Steelhead	Smith (1973)	≥.24	40-91	6/ .6-10.2
Rainbow trout	Smith (1973)	≥.18	48-91	.6-5.2
Cutthroat	Hunter (1973)	≥.06	11-72	.6-10.2
Brown trout	Thompson (1972)	≥.24	21-64	6/ .6-7.6

1/ From Bell (see text footnote 1).
2/ Unpublished data of D. W. Reiser, Idaho Coop. Fish Res. Unit, Moscow. 1978.
3/ Estimated from other criteria.
4/ See text footnote 3.
5/ No specific criteria established.
6/ From Hunter (1973).

spawning channels contain gravel that ranges from 1.9 to 15.2 cm (Pollock 1969). Bell (see footnote 1) states that, in general, the spawning bed in artificial channels should be composed of 80 percent 1.3-to 3.8-cm gravel with the balance up to 10.2 cm. Acceptable ranges of substrate size for various salmonids are summarized in table 4.

REDD AREA

Area of gravel substrate required for a spawning pair varies with the species (table 5). Burner (1951) proposed that a conservative estimate of the number of salmon a stream could accommodate could be obtained by dividing the area suitable for spawning by four times the average redd area. Redd area can be computed by measuring the total length of the redd (upper edge of pit to lower edge of tailspill) and the average of several equidistant widths.

WATER DEPTH AND VELOCITY

Preferred water depths and velocities for various spawning salmonids have been determined by measuring water depth and velocity over active redds (Sams and Pearson,[2/] Thompson 1972, Smith 1973, Hooper 1973, Hunter 1973, Reiser and Wesche 1977). These measurements were usually taken at the upstream edge of the redd because that point most closely approximates conditions before redd construction and reflects the depths and velocities selected by the fish. Preferred depth and velocity criteria have been variously defined: Thompson (1972) used a 90-to 95-percent confidence limit; Hunter (1973) used the middle 80-90 percent of the measurements; Smith (1973) used a two-sided tolerance limit within which there was 95-percent confidence that 80 percent of the measurements would occur with a normal distribution; others have simply listed ranges of depth and velocity. Water depth and velocity criteria for salmonids as defined by different investigators are found in tables 4 and 6.

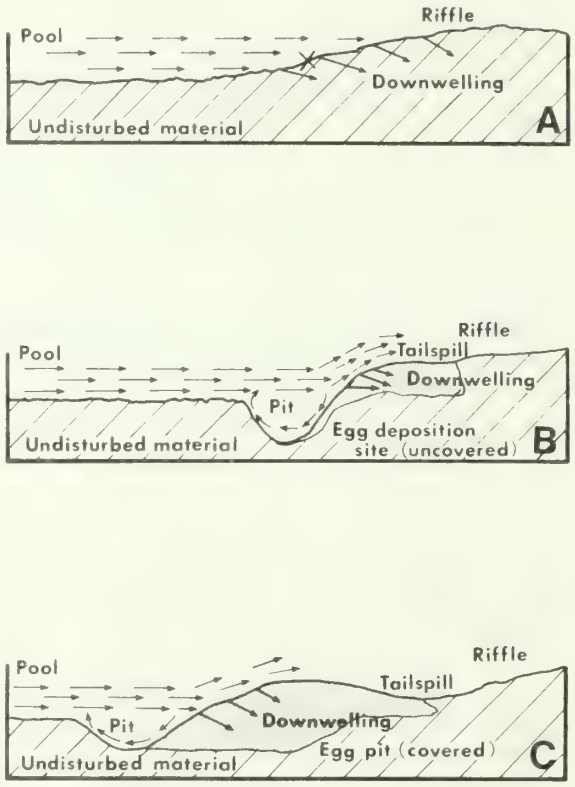


Figure 3—Longitudinal sections of spawning areas (from Reiser and Wesche 1977): A. Convexity of the substrate at pool-riffle interchange induces downwelling of water into the gravel. Area likely to be used for spawning is marked with an X. B. Redd construction results in negligible currents in the pit (facilitating egg deposition) and increased currents over and through (downwelling) the tailspill. C. Egg-covering activity results in the formation of a second pit which may also be used for spawning, as well as covering the eggs in the first pit. Increased permeability and the convexity of the tailspill substrate induces downwelling of water into the gravel, creating a current past eggs, bringing oxygen to them and removing metabolic wastes.

2/ Unpublished report, "A study to develop methods for determining spawning flows for anadromous salmonids," by R. E. Sams and L. S. Pearson. Oreg. Fish Comm., Portland, 1963.

Table 5—Average area of salmonid redds and area recommended per spawning pair in channels[1/]

Species	Source	Average area of redd	Area recommended per spawning pair
		------Square meters-----	
Spring chinook	Burner (1951)	3.3	13.4
Fall chinook	Burner (1951)	5.1	20.1
Summer chinook	Burner (1951)	5.1	20.1
Coho	Burner (1951)	2.8	11.7
Chum	Burner (1951)	2.3	9.2
Sockeye	Burner (1951)	1.8	6.7
Pink	Hourston and MacKinnon (1957)	.6	.6
Pink	Wells and McNeil (1970)	.6-.9	--
Steelhead	Orcutt et al. (1968)	5.4	--
Steelhead	Hunter (1973)	4.4	--
Rainbow	Hunter (1973)	.2	--
Cutthroat	Hunter (1973)	.09-.9	--
Brown	Reiser and Wesche (1977)	.5	--

1/ Modified from Clay (1961).

Many salmonids prefer to spawn at the pool-riffle interchange (Hazzard 1932, Hobbs 1937, Smith 1941, Stuart 1953, Briggs 1953). Tautz and Groot (1975) reported that chum salmon chose to spawn in an accelerating flow, such as that found at a pool-riffle interchange. By placing crystals of potassium permanganate on the gravel surface, Stuart (1953) demonstrated the presence of a downwelling current at these interchange areas and suggested that the current may assist the fish in maintaining its position with a minimum of effort. The gravel in these areas was easy to excavate and relatively free of silt and debris. The nature of currents before, during, and after spawning is shown in figure 3.

STREAMFLOW

Streamflow regulates the amount of spawning area available. D. H. Fry in Hooper (1973) summarizes the effect of discharge on the amount of spawning area in a stream.

> As flows increase, more and more gravel is covered and becomes suitable for spawning. As flows continue to increase, velocities in some places become too high for spawning, thus canceling out the benefit of increases in usable spawning area near the edges of the stream. Eventually, as flows increase, the losses begin to outweigh the gains, and the actual spawning capacity of the stream starts to decrease.

Table 6—Water depth, velocity, and size of substrate measured in spawning areas of salmonids

Species	Source	Depth	Velocity	Substrate	How and where developed	Remarks
		Meters	Cm/s	Centimeters		
Chinook salmon	Hamilton and Remington (1962)	>0.24	31	--	Oregon-Coquille River	
Fall chinook	Warner[1/]	.12-1.22	15-107	--	California-American, and Consumnes Rivers	
	Westgate[2/]					
	Kier (1964)	>.24	31-92	--	California-Feather, Eel, and Mad River Systems	
	Rantz (1964)					
	Horton and Rogers[3/]	≥.21	37-107		California-Van Duzen River	
	Chambers et al.[4/]	.30-.46	30-69		Washington-Columbia River and tributaries	$\bar{V}$ at 0.4 ft above bed
	Sams and Pearson[5/]	≥.18	.27-94	--	Oregon - 4 streams in Willamette River Basin	107 redds sampled; $\bar{V}$ at 0.63 depth or 0.2 ft and 0.8 depth from surface
	Thompson (1972)[6/]	≥.24	30-91	--	90-95% confidence interval; Oregon, wide range of streams	440 redds sampled; streams represented a wide variation of hydraulic characteristics
	Smith (1973)	≥.24	30-76	--	Tolerance interval; Oregon, 7 streams with varying hydraulic conditions	50 redds sampled; $\bar{V}$ at 0.4 ft above bed
Spring chinook	Chambers et al.[4/]	.46-.53	53-69	--	Washington-Columbia River and tributaries	$\bar{V}$ at 0.4 ft above bed
	Sams and Pearson[5/]	≥.18	.08-.85	--	Range; Oregon, 3 streams in Willamette River Basin	270 redds sampled; $\bar{V}$ at 0.6 ft depth or 0.2 ft and 0.8 ft depth from surface.
	Thompson (1972)[6/]	≥.24	30-91	--	90-95% confidence interval; Oregon, wide range of streams	158 redds sampled; streams representative of a wide variation of hydraulic characteristics
	Smith (1973)	≥.18	21-64	--	Tolerance interval; Oregon, 7 streams with varying hydraulic conditions	147 redds sampled; $\bar{V}$ at 0.4 ft above bed
	Reiser[7/]	≥.15	14-69	--	Range; Idaho, 5 small streams	58 redds sampled; $\bar{V}$ at 0.6 ft depth from surface
Summer chinook	Reiser [6/ 7/ 8/]	.30-.85	25-109	--	Range; Idaho, Salmon River	50 redds sampled; $\bar{V}$ at 0.6 ft depth from surface
Chum salmon	Thompson (1972)	≥.18	46-97	--	90-95% confidence interval; Oregon, on a wide range of streams	177 redds sampled; streams represented a wide variation of hydraulic characteristics
	Smith (1973)[6/]	≥.18	46-101	--	Tolerance interval; Oregon, 5 streams with varying hydraulic conditions	214 redds sampled; $\bar{V}$ at 0.4 ft above bed.
	Collings [9/]	.15-.53	21-101	--	--	$\bar{V}$ measured 0.4 ft above bed
Coho salmon	Chambers et al.[4/]	.30-.38	37-55	--	Washington, Columbia River and tributaries	Redds measured 0.4 ft above bed
	Sams and Pearson (1963)[5/]	≥.15	14-93	--	Range; Oregon, 4 streams	123 redds sampled; $\bar{V}$ at 0.6 ft depth or 0.2 ft and 0.8 ft depth from surface

Table 6—Water depth, velocity, and size of substrate measured in spawning areas of salmonids—(Continued)

Species	Source	Depth	Velocity	Substrate	How and where developed	Remarks
		Meters	Cm/s	Centimeters		
Coho salmon	Thompson (1972)[6/]	≥0.18	30-91	--	90-95% confidence interval; Oregon, 10-12 streams with varying hydraulic conditions	251 redds sampled; streams represent wide variation of hydraulic characteristics
	Smith (1973)	>.15	21-70	--	Tolerance interval; Oregon, 7 streams with varying hydraulic conditions	128 redds sampled; $\bar{V}$ measured 0.4 ft above bed
Pink salmon	Collings [6/ 9/]	.15-.53	21-101	--		$\bar{V}$ measured 0.4 ft above bed
Sockeye salmon	Chambers et al.[4/]	.30-.46	53	--	Washington	$\bar{V}$ at 0.4 ft above bed
	Clay (1961)	--	53-55	--		$\bar{V}$ at 0.4 ft above bed
Kokanee	Thompson (1972)	.12-.18	24-64	--	90-95% confidence interval; Oregon, wide range of streams	106 redds sampled; streams represent wide variation of hydraulic characteristics
	Smith (1973)[6/]	≥.06	15-73	--	Tolerance interval; Oregon, 3 streams with varying hydraulic conditions	106 redds sampled; $\bar{V}$ at 0.4 ft above bed
	Hunter (1973)	.09-.36	12-41	--	Middle 80% of range; Washington, flow 2-30 ft^3/s	177 redds sampled; $\bar{V}$ at 0.4 ft or 0.25-0.30 above bed
Steelhead trout		.35-.43	60-69	--	95% confidence interval; Oregon	51 redds sampled
Winter steelhead	Smith (1973)[6/]	≥.24	40-91	--	Tolerance interval; Oregon, 11 streams with varying hydraulic conditions	115 redds sampled; $\bar{V}$ at 0.4 ft above bed
	Engman[10/]	.10-≥.9	23-117	--	Range; Washington	62 redds sampled
	Hunter (1973)	.21-.70	37-101	0.64-10.16	Middle 90% of range; Washington, 19 streams with varying hydraulic conditions	114 redds sampled; $\bar{V}$ at 0.4 ft or 0.25-0.30 ft above bed
	Hunter (1973)	.12-.36	44-109	0.64-12.70	Range; Washington	19 redds sampled; $\bar{V}$ at 0.4 ft or 0.25-0.30 ft above bed
	Hunter[11/]	.23-.50	41-108	--	Range; Washington, on streams of 180 ft^3/s	30 redds sampled; $\bar{V}$ at 0.4 ft or 0.25-0.30 ft above bed
	Hunter[11/]	.14-.20	25-34	--	Range; Washington, Satsop River	4 redds sampled; $\bar{V}$ at 0.4 ft or 0.25-0.30 ft above bed
Summer steelhead	Smith (1973)	≥.24	43-97	--	Tolerance interval; Oregon, Deschutes River	90 redds sampled; $\bar{V}$ 83 redds sampled D; $\bar{V}$ at 0.4 ft above bed
	Orcutt et al. (1968)	.21-≥1.52	24-55	1.27-10.16	Range; Idaho, 6 streams in Clearwater and Salmon River watersheds	54 redds sampled; $\bar{V}$ measured at the surface

Table 6—Water depth, velocity, and size of substrate measured in spawning areas of salmonids —(Continued)

Species	Source	Depth	Velocity	Substrate	How and where developed	Remarks
		Meters	Cm/s	Centimeters		
Summer steelhead	Reiser[8/]	0.12-.41	38-100	--	Range; Idaho, 3 streams	46 redds sampled; $\bar{V}$ measured at 0.6 ft depth from surface
Rainbow trout	Smith (1973)[6/]	≥.18	48-91	0.64-5.18	Tolerance interval; Oregon, Deschutes River	51 redds sampled; $\bar{V}$ at 0.4 ft above bed
	Hooper (1973)	.21-.33	43-82	.64-7.62	Range; California, Feather River	10 redds sampled; $\bar{V}$ at 0.21 above bed
	Bovee (1974)	.15	43-82	--	Estimated from literature	
	Waters (1976)	.09-.90	21-91	--	California, Pit River	
	Hartman (1969)	--	50-90	--	British Columbia, Kootenay Lake	
Cutthroat trout	Hooper (1973)	--	30-91	.16-.64	Range; California	
	Cedarholm (in Hunter 1973)	.08-.15	8-26	--	Range; Washington	3 redds sampled
(resident)	Hunter (1973)	.06-.27	11-38	.64-5.08	Range; Washington, streams 0.5-2.0 ft^3/s	23 redds sampled; $\bar{V}$ at 0.4 ft or 0.25-0.30 ft from bed
(sea-run)	Hunter (1973)	.12-.40	15-56	.64-10.16	Range; Washington, streams 5.0-15.0 ft^3/s	16 redds sampled; $\bar{V}$ at 0.4 ft or 0.25-0.30 ft from bed
Brown trout	Smith (1973) (Hunter 1973)	≥.24	20-68	.64-7.62	Tolerance interval; Oregon, 5 streams with varying hydraulic conditions	115 redds sampled; $\bar{V}$ at 0.4 ft from bed
Brown trout	Thompson (1972)[6/]	≥.24	21-64	--	90-95% confidence interval; Oregon, on a wide range of streams	115 redds sampled
	Hooper (1973)	--	30-91	.64-7.62	Range; California	
	Bovee (1974)	≥.15	40-52	--	Estimated from literature	
	Reiser and Wesche (1977)	≥.09	14-46	.64-7.62	Middle 80% of range; Wyoming, 5 small streams	121 redds sampled; $\bar{V}$ at 0.6 ft depth from surface

[1/] Unpublished report, "The relationship between flow and available salmon spawning gravel on the American River below Nimbus Dam," by K. Warner. Calif. Dep. Fish and Game Admin., Sacramento, 1953.

[2/] Unpublished report, "The relationship between flow and usable salmon spawning gravel, Consumnes River, 1956," by J. Westgate. Calif. Dep. Fish and Game, Inland Fish. Admin. Rep. 58-2, Sacramento, 1958.

[3/] Unpublished report, "The optimum stream flow requirements for king salmon spawning in the Van Duzen River, Humboldt County, California," by J. L. Horton and D. W. Rogers. Calif. Dep. Fish and Game, Water Proj. Branch Admin. Rep. 69-2, Sacramento, 1969.

[4/] Unpublished report, "Research relating to study of spawning grounds in natural areas," by J. S. Chambers, G. H. Allen, and R. T. Pressey. Wash. Dep. Fish., Olympia, 1955.

[5/] See text footnote 2.

[6/] Recommended spawning criteria.

[7/] Unpublished data of D. W. Reiser, Idaho Coop. Fish. Res. Unit, Moscow, 1977.

[8/] See footnote 2, table 4.

[9/] See text footnote 3.

[10/] Unpublished progress report, steelhead redd study, by R. G. Engman. Wash. State Dep. Game, Olympia, 1970.

[11/] Personal communication, J. W. Hunter, Wash. Dep. Game, Olympia, 1976.

If spawning area is plotted against streamflow, the curve will usually show a rise to a relatively wide plateau followed by a gradual decline.

Using the criteria described, methods have been developed for recommending stream discharges for spawning. Figures 4 and 5, taken from Collings (1972), exemplify the process of depth and velocity contouring to determine the area suitable for spawning at a given discharge. Another method (Thompson 1972) uses cross channel transects on spawning bars and consists of quantifying the width of the stream at different flows that meet depth and velocity criteria (fig. 6). When measurements have been taken over a wide range of flows, a graph is plotted of flow versus suitable spawning areas (Collings 1972, and fig. 7) or usable width (Thompson 1972, and fig. 8). The optimum spawning flow is defined as the discharge at which the largest spawning area or usable width occurs. Detailed descriptions of spawning flow methodologies are described by Sams and Pearson (see footnote 2), Thompson (1972), Collings (1972, 1974[3/]), Waters (1976), and Stalnaker and Arnette (1976).

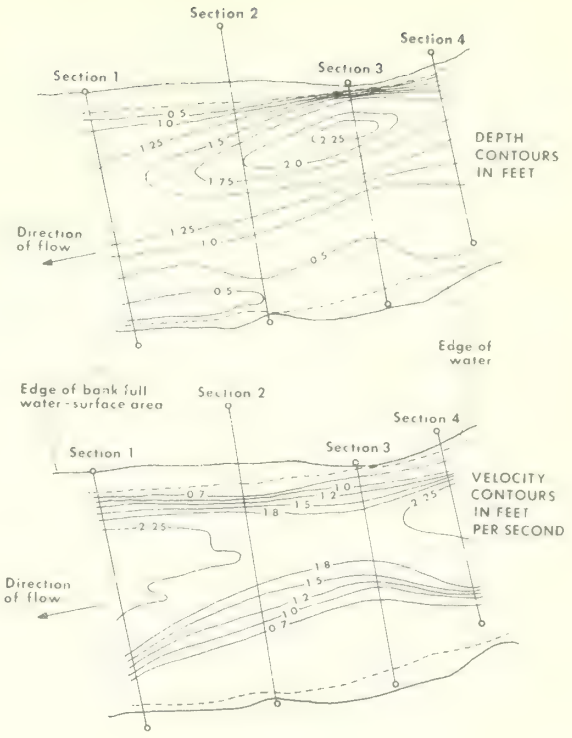


Figure 4—Example of water depth and velocity contouring for one river discharge in a study reach of the North Nemah River (from Collings 1972).

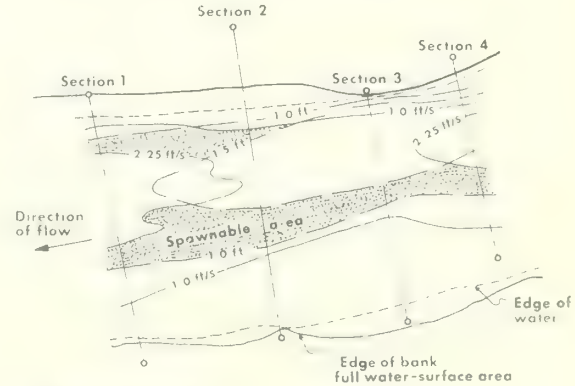


Figure 5—Determining area of study reach that is preferred for spawning by fall chinook salmon at one river discharge, North Nemah River (from Collings 1972).

3/ Unpublished report, "Generalization of spawning and rearing discharges for several Pacific salmon species in western Washington," by M. R. Collings. U.S. Geol. Surv., open file report. 1974.



SPAWNING BAR CROSS SECTION

Station	Depth feet	Velocity feet per second
1	0.4	1.4
2	.6	1.6
3	.7	1.9
4	.9	2.3
5	1.1	3.1
6	1.0	2.6
7	.8	2.0
8	.7	1.4
9	.6	.9

Spawning flow criteria

Minimum depth = 0.6 ft

Velocity = less than 3.0 but greater than 1.0 ft/s

Flow = width x mean depth x mean velocity

Flow = 25 ft x 0.75 ft x 1.93 ft/s

= 36 ft^3/s

Stream width usable for spawning

Usable width = $\frac{\text{stream width}}{10}$ x usable stations

= $\frac{25 ft}{10} \times 6$

= 15.0 ft

Figure 6—Transect method of determining stream width usable for spawning (from Thompson 1972).

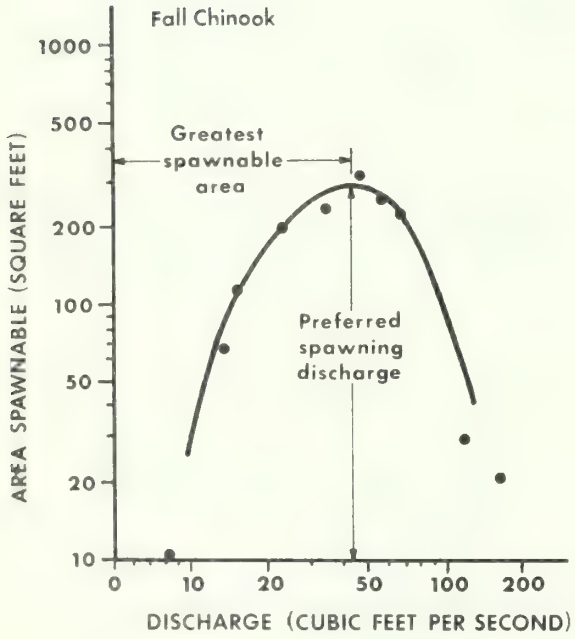


Figure 7—Method (usable area technique) for selecting preferred spawning discharge, North Nemah River (from Collings 1972).

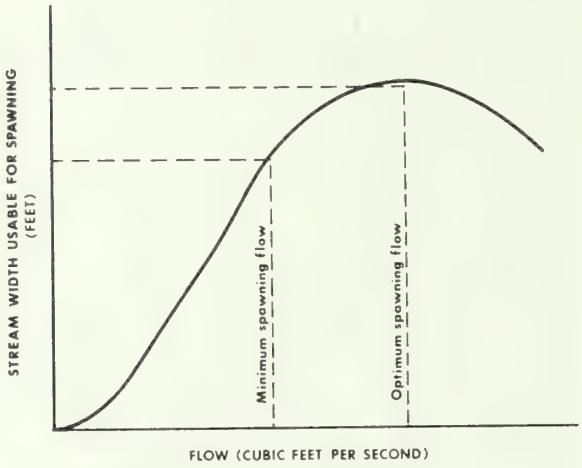
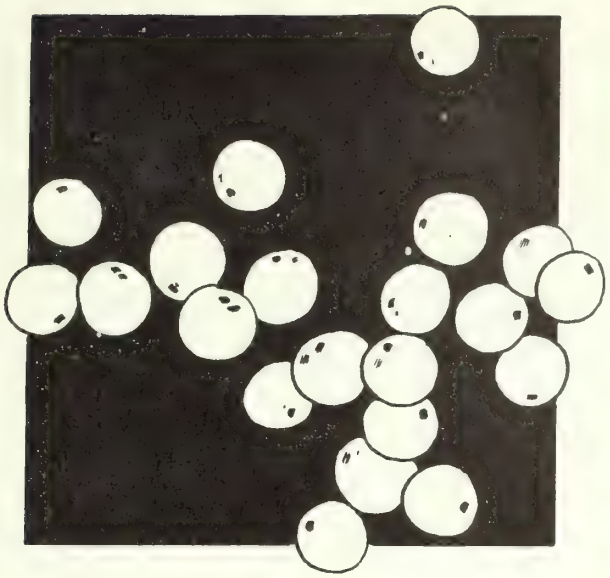


Figure 8—Method (usable width technique) for determining spawning flow (from Thompson 1972).



INCUBATION

Although incubation is inextricably tied to spawning, the habitat requirements of embryos during incubation are different from those of adults while spawning and warrant a separate discussion. When an adult fish selects a spawning site, the incubation environment is also being selected. Successful incubation and emergence of fry, however, is dependent on both extragravel and intragravel chemical, physical, and hydraulic parameters--dissolved oxygen (DO), water temperature, biochemical oxygen demand (BOD) of material carried in water and in substrate, substrate size (percentage fines), channel gradient, channel configuration, water depth (head), surface water discharge and velocity, permeability, porosity, and apparent velocity in gravel.

SURFACE STREAM-INTRAGRAVEL RELATION

Interchange of water in a stream with that in streambed gravels has been demonstrated by Stuart (1953), Sheridan (1962), Vaux (1962). Vaux (1962) stated that the initial source of oxygen in intragravel water is the atmosphere and listed the following three steps for transport of oxygen to the intragravel environment:

- Dissolution of oxygen through air-water interface into stream water.
- Transport of oxygenated water to the stream bottom.
- Interchange of oxygenated water from the stream into the porous gravel interior.

Factors that control the water interchange between stream and gravel bed are: stream surface profile, gravel permeability, gravel bed depth, and irregularity of the streambed surface (Vaux 1962, 1968). Sheridan (1962) noted in salmon spawning areas in southeast Alaska, that ground water contained very little oxygen and that the oxygen content of intragravel water decreased with gravel depth; thus the major source of oxygen in intragravel water is the stream itself. Wells and McNeil (1970) attributed high intragravel oxygen in pink salmon spawning beds to high permeability of the substrate and stream gradient.

Intragravel water temperatures are similarly influenced by temperatures of the stream. Ringler (1970) and Ringler and Hall (1975) observed that temperatures of intragravel water lagged 2-6 h behind those of surface waters in attaining diurnal maximum--a function of the interchange rate of surface and intragravel water.

Apparent velocity (velocity of water moving through gravel)

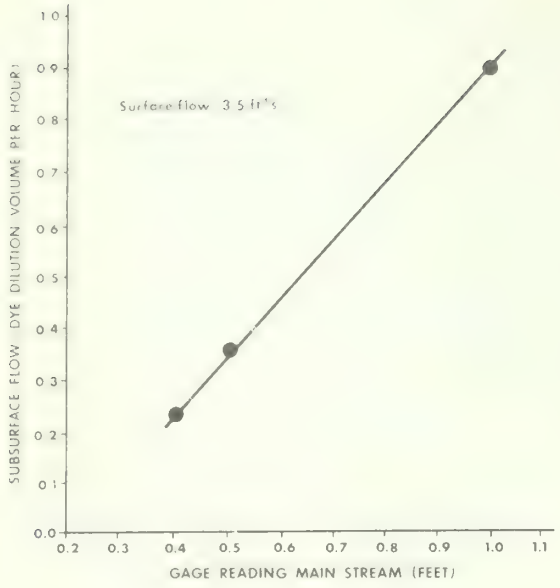


Figure 9—Relation between subsurface water flow 30 cm (12 in) in a controlled-flow side channel and main stream gage readings. The subsurface flow varied with changes in discharge of the main stream adjacent to the controlled-flow side channel (from Wickett 1954, courtesy of the Journal of the Fisheries Research Board of Canada).

is a function of the hydraulic head and the permeability of the gravel (Coble 1961). Thus, as depth of surface water increases, a corresponding increase in apparent velocity can be expected. Wickett (1954) found a direct relation between gage height readings in a stream and subsurface flow (fig. 9). Reduction in permeability from fine sediment deposition will reduce both the interchange of surface and intragravel water and the apparent velocity of the intragravel water (Gangmark and Bakkala 1960, Wickett 1962, Cooper 1965).

DISSOLVED OXYGEN

Critical concentrations of dissolved oxygen have been experimentally determined for salmonid embryos at different

Table 7—Critical levels of dissolved oxygen for salmonid embryos at various stages of development

Source	Species	Stage of development	Days	Temperature units[1/]	Critical value of dissolved oxygen
					Mg/l
Wickett (1954)	Chum salmon	Pre-eyed	0	--	0.72
		Pre-eyed	5	--	1.67
		Pre-eyed	12	--	1.14
		Faintly eyed	85	--	3.70
Alderdice et al. (1958)	Chum salmon	--	--	4.0	[2/].72
		--	--	4.8	[2/]1.67
		--	--	48.0	[2/]1.14
		--	--	121.2	[2/]3.96
		--	--	162.1	[2/]3.70
		--	--	268.2	5.66
		--	--	353.0	6.60
		--	--	452.4	7.19
Lindroth (1942)	Atlantic salmon	Doomed	--	--	.76
		Nearly hatching	--	--	5.80
		Hatching	--	--	10.00
Hayes et al. (1951)	Atlantic salmon	Eyed	25	--	3.1
		Hatching	50	--	7.1

1/ A temperature unit equals 1°F above freezing (32°F) for a period of 24 h.
2/ From Wickett (1954).

developmental stages (Lindroth 1942, Hayes et al. 1951, Wickett 1954, Alderdice et al. 1958). Critical oxygen levels defined by Alderdice et al. (1958) are those that barely satisfy respiratory demands (table 7). Doudoroff and Warren (1965) believe the critical levels in table 7 are unreliable, because they found that embryos exposed to dissolved oxygen levels below saturation throughout development were smaller and that hatching was delayed or occurred prematurely. From laboratory tests with coho, chum, and chinook, and steelhead eggs by Alderdice et al. (1958), Silver et al. (1963), and Shumway et al. (1964), the following summary of oxygen concentration and egg development has been prepared:

- Sac fry from embryos incubated in low and intermediate oxygen concentrations were smaller and weaker than sac fry reared at higher concentrations, and thus they may not survive as well as larger fry (Silver et al. 1963, and figs. 10 and 11).

- Reduced oxygen concentrations lead to smaller newly hatched fry and a lengthened incubation period (Shumway et al. 1964, and figs. 12 and 13).

- Low oxygen concentrations in the early stages of development may delay hatching, increase the incidence of anomalies, or both. Low oxygen concentration during the latter stages of development may stimulate premature hatching (Alderdice et al. 1958).

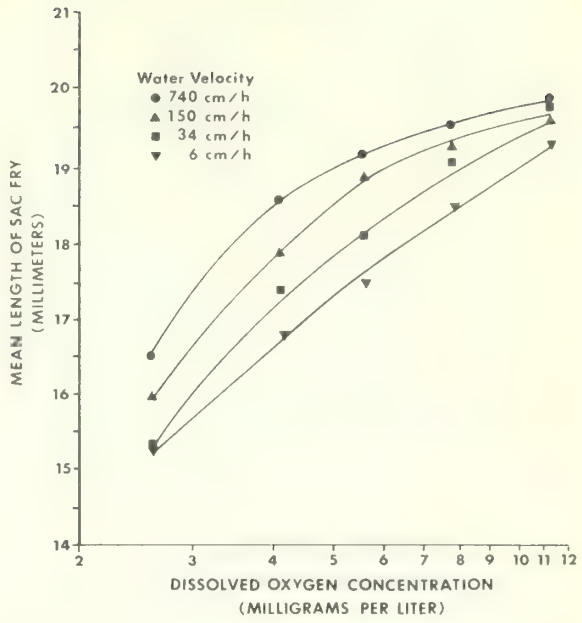


Figure 10—Relation between mean lengths of steelhead trout sac fry when hatched and dissolved oxygen concentrations at which the embryos were incubated at different water velocities and at 9.5°C (from Silver et al. 1963).

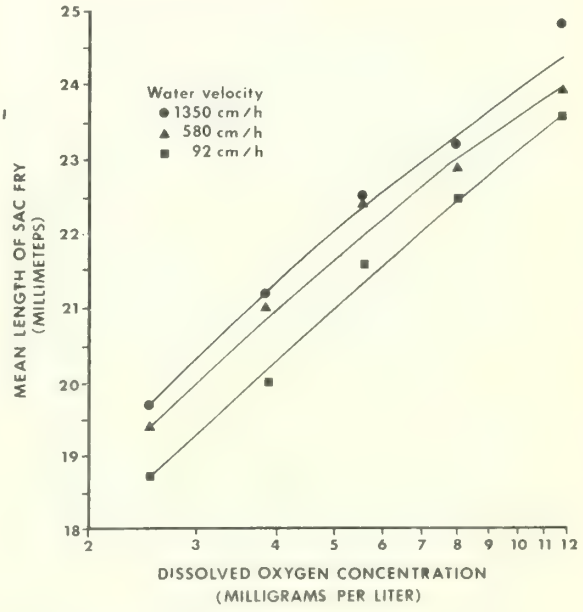


Figure 11—Relation between mean lengths of chinook salmon sac fry at hatching and dissolved oxygen concentrations at which the embryos were incubated at different water velocities and at 11°C (from Silver et al. 1963).

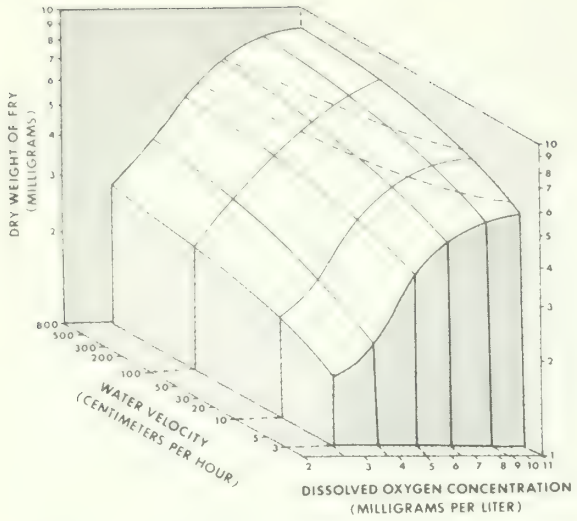


Figure 12—Three-dimensional diagram of effect of oxygen concentration and water velocity on the mean dry weights of newly hatched coho salmon fry. The two broken lines (curves) delimit the reduced oxygen concentrations at different water velocities, and also the reduced velocities at different oxygen concentrations that resulted in reductions of the dry weights of fry to less than 80 percent (upper broken line) and less than 67 percent (lower broken line) of the mean weight of fry that hatched at the highest oxygen concentration and water velocity tested (from Shumway et al. 1964).

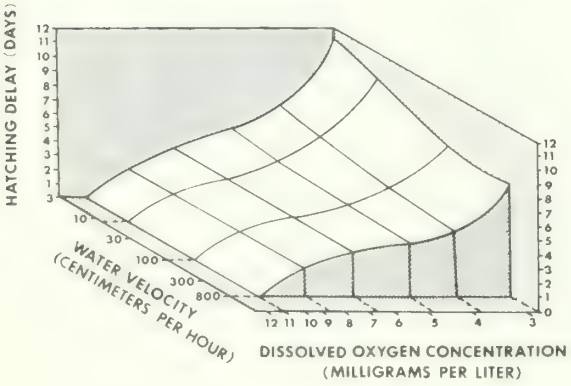


Figure 13—Three-dimensional diagram of "hatching delay" (median hatching time, in days, minus 44) of coho salmon fry in relation to both oxygen concentration and water velocity (from Shumway et al. 1964).

In field studies, Coble (1961) found a positive correlation between steelhead embryo survival and intragravel dissolved oxygen content (fig. 14). A similar relation was reported by Phillips and Campbell (1961) for coho salmon and steelhead (fig. 15). Based on their field experiments, Phillips and Campbell concluded that intragravel oxygen concentration must average 8 mg/l for high survival of coho salmon and steelhead embryos. Brannon (1965) compared newly hatched sockeye salmon fry developed at three different oxygen levels, and found length and other anatomical differences in the three groups (table 8); however, those raised in low oxygen concentrations eventually attained nearly the same weight by the fry stage as did those incubated

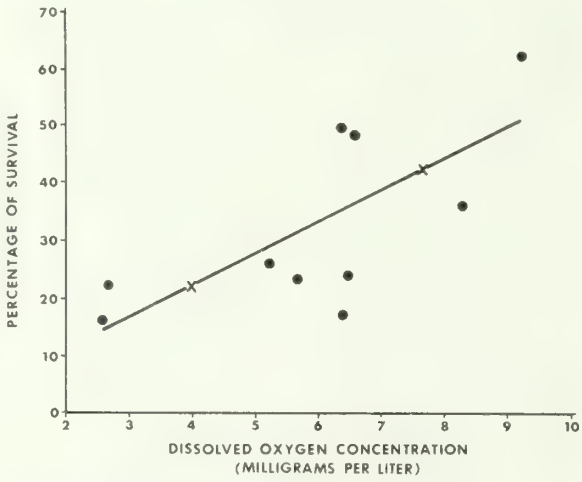


Figure 14—Relation between dissolved oxygen concentration and embryo survival (from Coble 1961).

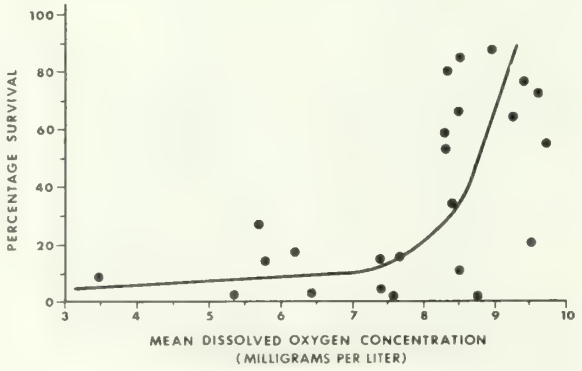


Figure 15—Relation of mean dissolved oxygen to survival of coho embryos, Needle Branch, December 20, 1960, to February 28, 1961 (from Phillips and Campbell 1961).

Table 8—Characteristics of alevins at hatching after being incubated in three oxygen concentrations (from Brannon 1965)

Description	O_2 concentration (mg/l)		
	3.0	6.0	11.9
Temperature units to 50% hatching	1200	1200	1200
Length in millimeters	16.3	18.6	19.7
Yolk sac shape	Spherical	Longitudinal	Longitudinal
Pigmentation	Lightly on head	On head and starting on back	On head and back
Visibility of the dorsal and anal fin rays	Not visible	Distinguish-able	Readily visible
Caudal fin development	Forming	Forming	Well advanced

in water fully saturated with oxygen. Although dissolved oxygen concentrations required for successful incubation depend on both species and developmental stage, concentrations at or near saturation with temporary reductions no lower than 5.0 mg/l are recommended for anadromous salmonids.

TEMPERATURE

There are upper and lower temperature limits (thresholds) for successful incubation of salmonid eggs (table 3). Combs and Burrows (1957) and Combs (1965) noted that pink and chinook salmon eggs could tolerate long periods of low temperature, provided the initial temperature was above 6.0°C and embryogenesis had proceeded to a particular developmental stage. Combs and Burrows (1957) believed salmon eggs deposited in water colder than 4.5°C would not produce as viable a fish as eggs spawned into warmer water.

In many streams containing incubating salmonid eggs, water temperatures are colder than 4.5°C during the winter; eggs develop normally and successfully, however, because spawning and initial embryo development occur when temperatures are warmer.

Extremely cold water and air temperature can cause mortality among incubating eggs and fry by the formation of frazil or anchor ice that reduces water interchange. Anchor ice normally forms in shallow water typical of spawning areas and may completely blanket the surface of the substrate and thereby prevent water interchange between stream and gravel. In addition, ice dams may form that can impede flow or even dewater spawning areas. Subsequent melting of the dam may cause floodlike conditions resulting in the displacement and scouring of redds. In an egg planting experiment, Reiser and Wesche (1977) found eggs in

Vibert boxes completely frozen even though buried 15 cm in the substrate and covered with more than 13 cm of water. Anchor ice had formed at least twice during the incubation period. Neave (1953) and McNeil (1966) also noted the problems of freezing on egg survival.

BIOCHEMICAL OXYGEN DEMAND

The oxygen demand of organic matter in the stream may reduce the oxygen concentration, particularly in the intragravel environment. The impact of organic matter in a stream depends on the chemical, physical, and hydraulic characteristics (for example, dissolved oxygen content, temperature, and reaeration capability) of the stream. Excessive recruitment of organic material to a stream may result in reduced oxygen concentrations and detrimental impacts on eggs.

APPARENT VELOCITY

The single most important hydraulic component in the intragravel environment used for egg incubation is apparent velocity, defined as the rate of seepage and expressed as the volume of liquid flowing per unit time through a unit area normal to the direction of flow (Terhune 1958, Coble 1961, Vaux 1968). Apparent velocity is important in bringing dissolved oxygen to the eggs and removing metabolic waste products.

High oxygen levels do not, in themselves, guarantee high egg survival. In two redds with similar dissolved oxygen concentrations but different apparent velocities, embryonic development may be better in the redd with the higher rate of water exchange (Coble 1961). Coble states that, in general, when apparent velocities are low, oxygen concentrations will be low and, when they are high, oxygen levels are usually high. Others have found egg survival related to apparent velocity--for example, Pyper (in Cooper 1965) in sockeye eggs (fig. 16), Coble (1961) in steelhead (fig. 17), Gangmark and Bakkala (1960) in chinook, Wickett (1962) in pink salmon, and Phillips and Campbell (1961) in coho and steelhead. In the last study, high egg survivals were associated with apparent velocities of more than 20 cm/h. Wickett (1962) found low survival in areas where apparent velocities were 0.5-1.5 cm/h and high survivals where velocities were more than 7 cm/h. Silver et al. (1963) and Shumway et al. (1964) related apparent velocity to size of fry at a hatchery. Silver et al. found that size of steelhead and chinook fry depended on apparent velocities, even at velocities as high as 740-1350 cm/h. Shumway et al. found that reduced velocities (3-10 cm/h) resulted in decreased size of fry at all oxygen levels tested (2.5-11.5 mg/l).

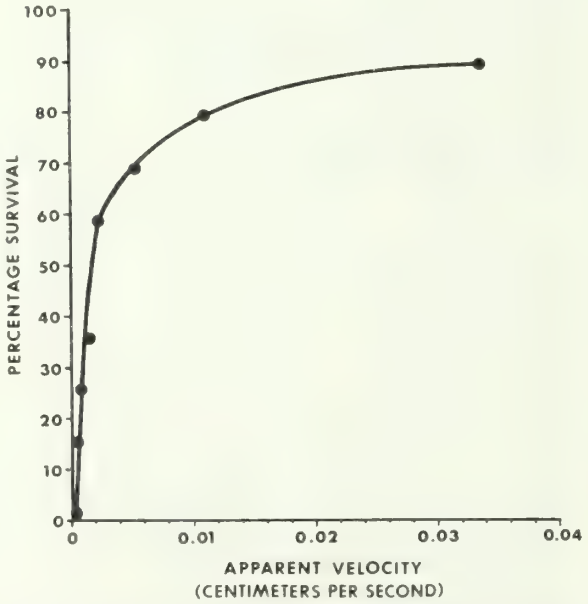


Figure 16—Relation between rate of flow of water through a gravel bed and the survival of eyed sockeye eggs in the gravel (from Cooper 1965).

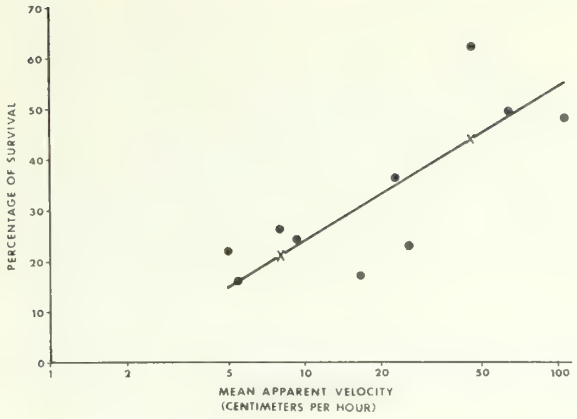


Figure 17—Relation between apparent velocity and embryo survival (from Coble 1961).

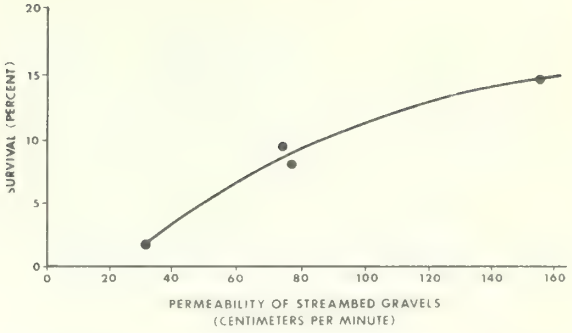


Figure 18—Observed relation reported by Wickett (1958) between permeability of spawning beds and survival of pink and chum salmon to the migrant fry stage (from McNeil and Ahnell 1964).

SUBSTRATE MATERIALS

Spawning bed materials also influence the development and emergence of fry. Permeability of the substrate (the ability of a material to transmit fluids) sets the range of subsurface water velocities (Wickett 1962). Low permeabilities result in lower apparent velocities and reduced oxygen delivery to and metabolite removal from the eggs. Wickett (1958) found that survival of pink and chum salmon eggs was related to permeability (fig. 18). McNeil and Ahnell (1964) concluded that highly productive spawning streams had gravels with high permeability. Permeability was high (24,000 cm/h) when bottom materials had less than 5 percent (by volume) sands and silts that passed through a 0.833 mm sieve and was relatively low (less than 1 300 cm/h) when fine sediments made up more than 15 percent of the bottom material.

Successful fry emergence is hindered by excessive amounts of sand and silt in the gravel. Even though embryos may hatch and develop, survival will be poor if they cannot emerge. Koski (1966) examined redds

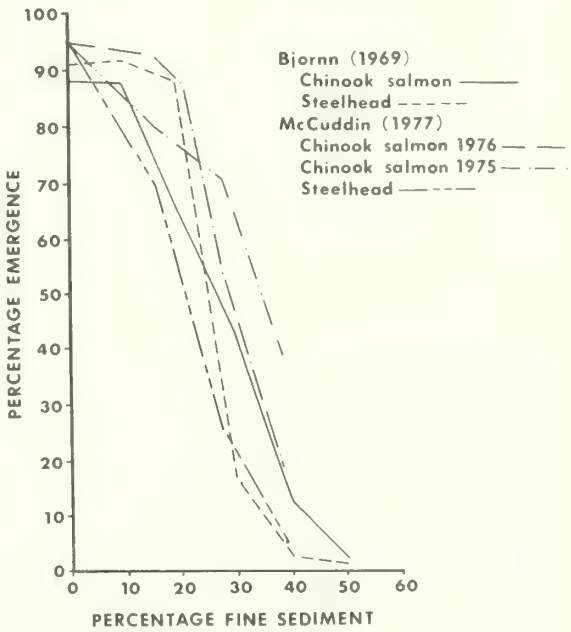


Figure 19—Percentage emergence of fry from newly fertilized eggs in gravel-sand mixtures. Fine sediment was granitic sand with particles less than 6.4 mm.

where eggs had developed normally but the hatched fry were unable to emerge because of sediment. Phillips et al. (1975) found an inverse relation between quantity of fine sediments and fry emergence. Bjornn (1969) and McCuddin (1977) demonstrated that survival and emergence of chinook salmon and steelhead embryos were reduced when sediments less than 6.4 mm in diameter made up 20-25 percent or more of the substrate (figs. 19 and 20).

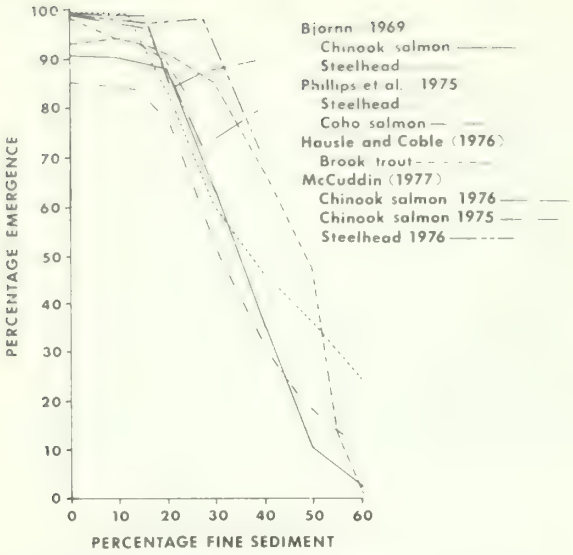


Figure 20—Percentage emergence of swim-up fry placed in gravel-sand mixtures. Sediments were 1- to 3-mm particles in the study by Phillips et al. (1975), less than 2 mm in the study by Hausle and Coble (1976), and less than 6.4 mm in studies by Bjornn (1969) and McCuddin (1977).

STREAMFLOW

Streamflow requirements of incubating salmonid eggs are largely unknown partly because of the lack of information on interactions of surface flows and the intragravel environment. According to Stalnaker and Arnette (1976), most agencies that are concerned with fish habitat do not attempt to deal specifically with streamflows for incubation but only for spawning, on the assumption that flows suitable for spawning will be suitable for incubation. U.S. Fish and Wildlife Service personnel at times have recommended an increase in flow for incubation over that present at spawning (Hale in Hooper 1973). Oregon Department of

Table 9. General habitat guidelines for incubation of salmonid embryos

Parameter	Recommended limit
Dissolved oxygen	At or near saturation; lower threshold - 5.0 mg/l
Water temperature	4°-14°C[1/]
Permeability	More than 1 300 cm/h
Sediment composition	Less than 25% by volume of fines ≤6.4 mm
Surface flow	Sufficient to allow fry to emerge
Surface velocity	Velocities should be less than those that scour the redds and displace spawning bed materials
Apparent velocity	More than 20 cm/h
Biochemical oxygen demand	Should not diminish or deplete the dissolved oxygen content below stated levels

1/ Upper and lower values are threshold temperatures. Eggs will develop normally at lower temperatures provided initial development has progressed to where they become tolerant of cold.

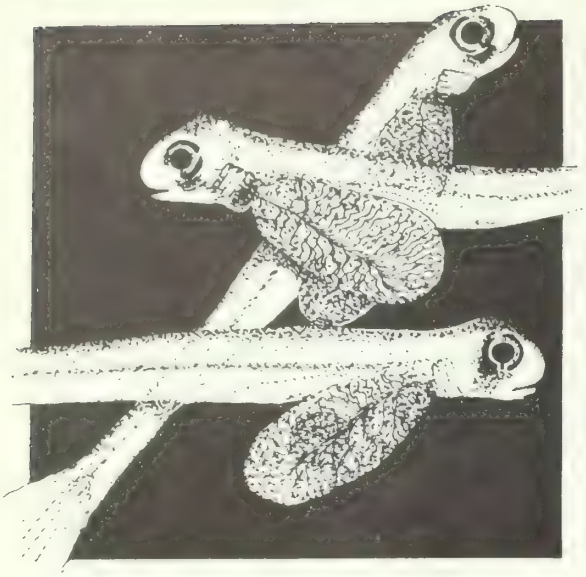
Fish and Wildlife personnel use field observations to judge recommended incubation flows that are often equivalent to about two-thirds of the spawning flow. Thompson (1972), however, pointed out that the two-thirds rule does not always hold, and adequate flow depends largely on the particular stream. Research is currently underway in Idaho and Alaska to quantify the instream flow needs for successful incubation and hatching of salmonid eggs.

Forest practices, such as roadbuilding and clearcut logging, may increase the water yield from a watershed and sometimes contribute to the flooding in a stream (Rothacher 1971). Rapid fluctuations in streamflow can decrease egg survival by disturbing redds and thereby crushing and dislodging eggs. Gangmark and Broad (1956) attributed complete mortality of planted chinook eggs to stream flows that increased 100 times during egg planting. Other investigators have also noted the deleterious effects of flooding on egg survival (Hobbs 1937, Neave 1953, Gangmark and Bakkala 1960, Sheridan and McNeil 1968). As noted by Chapman (1962), abnormally high flow at the wrong time causes increased mortality. Moderately high flows are beneficial in assuring adequate interchange of intragravel and surface waters and improving the oxygen supply to embryos.

Because species-specific incubation criteria have not been developed, generalization is needed to define suitable incubation for anadromous salmonids. General guidelines for salmonid incubation based on the preceding information are presented in table 9.







JUVENILE REARING

Habitat requirements of juvenile anadromous fish in streams vary with species, size, and time of year. The rearing period extends from fry emergence to seaward migration and can range from a few days for chum and pink salmon to 3 or 4 years for steelhead trout. For fish that spend an extended time in fresh water, the quantity and quality of the habitat sets the limits on the number of fish that can be produced. Important habitat components for juvenile salmon and trout are fish food production areas, water quality and quantity, cover, and space. The interaction of some of these habitat components with biological features of the environment have been studied (Giger 1973, Hooper 1973), but specific criteria for rearing habitat have not been completely defined for anadromous salmonids in streams. We will discuss features of stream habitat and relate them to salmonid production where warranted by the data available.

FISH FOOD PRODUCTION AREAS

Density of juvenile anadromous salmonids may be regulated by the abundance of food (perhaps expressed as competition for space) in some streams (Chapman 1966). Food for these salmonids comes primarily from the surrounding land and from the substrate within the stream; the relative importance of terrestrial and aquatic insects varies with stream size, location, riparian vegetation, and time of year.

VELOCITY

According to Scott (1958) and Allen (1959), velocity is the most important parameter in determining the distribution of aquatic invertebrates in streams. Most aquatic invertebrates live in a vertical boundary layer on the stream substrate where velocities are near zero. Water velocities just above the boundary layer, however, are typical of riffle areas (Pearson et al.,[4/] Needham and Usinger 1956, Delisle and Eliason 1961, Arthur 1963, Ruggles 1966, Kimble and Wesche 1975, and table 10).

DEPTH

The influence of water depth on aquatic insect production is poorly understood, but Needham and Usinger (1956) and Kennedy (1967) found the largest numbers of organisms in shallow areas typical of riffles. In a study by Kimble and Wesche (1975), mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) were found in depths less than

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[4/] Unpublished report, "Factors affecting the natural rearing of juvenile coho salmon during the summer low flow season," by L. S. Pearson, K. R. Conover, and R. E. Sams. Fish. Comm. Oreg., Portland, 1970.

Table 10—Water velocity criteria for aquatic invertebrates

Source	Velocity range
	Meters per second
Kennedy (1967)[1/]	0.15-0.91
Pearson et al.[1/]	.15-1.22
Surber (1951)	.15-1.07
Delisle and Eliason (1961)	.15-.91
Hooper (1973)	.46-1.07
Giger (1973)	.30-.61
Needham and Usinger (1956)	.61-1.07
Kimble and Wesche (1975)	>.15
Thompson (1972)	.30-.46

1/ See text footnote 4.

0.3 m. Hooper (1973) reported that areas of highest invertebrate productivity usually occur in streams at depths between 0.15 and 0.9 m if substrates and velocities are suitable.

SUBSTRATE

Stream substrate composition is another factor that regulates the production of invertebrates; highest production is from gravel and rubble-size materials (Needham 1934, Linduska 1942, Smith and Moyle 1944, Sprules 1947, Ruttner 1953, Cummins 1966, Thorup 1966, Kennedy 1967, Corning 1969, Hynes 1970). Substrate size is a function of water velocity, with larger materials (rubble and boulder) associated with fast currents and smaller materials (silt and sand) with slow-moving water.

Pennak and Van Gerpen (1947) noted a decrease in number of benthic invertebrates in the progression rubble-bedrock-gravel-sand. A similar decrease was noted by Kimble and Wesche (1975) in the series rubble-coarse gravel-sand and fine gravel-silt. Sprules (1947) reported that, in general, the diversity of available cover for bottom fauna decreases as the size of inert substrate particles decreases. Rubble seems to be the most productive substrate. Large rubble substrate provides insects with a firm surface to cling to and also provides protection from the current.

The importance of insects produced in riffles as food for fish is documented by Waters (1969), and Pearson et al. (see footnote 4) reported higher coho production per unit area in pools with large riffles upstream than in pools with small riffles upstream.

Velocity, depth, and substrate criteria for optimum fish food production are:

Velocity	0.46-1.07 m/s
Depth	0.46-0.91 m
Substrate	Composed largely of coarse gravel (3.2-7.6 cm) and rubble (7.6-30.4 cm)

RIPARIAN VEGETATION

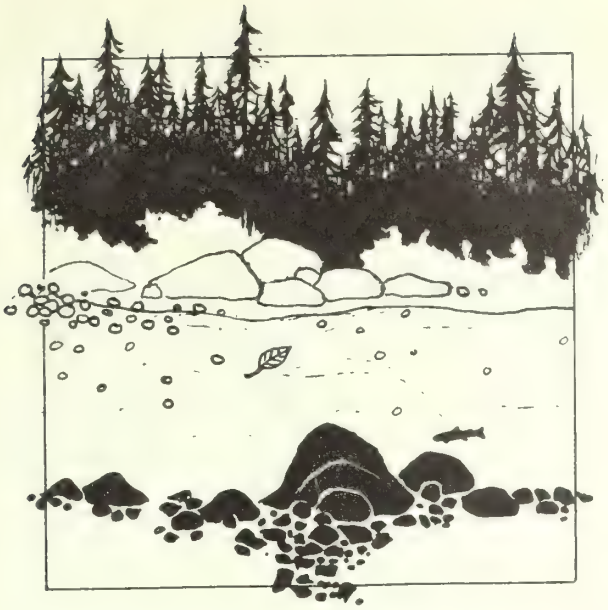
Terrestrial insects are also important food items for

salmonids. They may enter streams by falling or being blown off riparian vegetation and by being washed in from shoreline areas by wave action or rapid flow fluctuations (Mundie 1969, Fisher and LaVoy 1972). Once in the stream, these organisms are entrained by the current, become a part of the drift, and are fed upon by fish (Surber 1936, Kelley et al.,[5/] Delisle and Eliason 1961, Kennedy 1967, Allen 1969). Plant material that falls into the stream from riparian vegetation may be an important source of food to aquatic invertebrates. Sekulich and Bjornn (1977) found that terrestrial insects were second only to chironomids (midges) in importance as food for juvenile anadromous salmonids in the streams they studied. Groups of insects and other arthropods that may become a part of terrestrial drift include: Diptera (flies), Orthoptera (grasshoppers and crickets), Coleoptera (beetles), Hymenoptera (bees, wasps, and ants), Lepidoptera (butterflies and moths), Homoptera (leaf hoppers), and Araneida (spiders).





[5/] Unpublished report, "A method to determine the volume of flow required by trout below dams: a proposal for investigation," by D. W. Kelley, A. J. Cordone, and G. Delisle. Calif. Dep. Fish and Game, Sacramento, 1960.



WATER QUALITY

Temperature

Salmonids are cold water fish with definite temperature requirements during rearing. Water temperature influences growth rate, swimming ability, availability of dissolved oxygen, ability to capture and use food, and ability to withstand disease outbreaks. Brett (1952) lists the upper lethal temperature for chinook, pink, sockeye, chum, and coho salmon as 25.1°C. The upper lethal temperature for rainbow trout lies between 24° and 29.5°C depending on oxygen concentration, fish size, and acclimation temperature (McAfee 1966). Slightly lower temperatures can be tolerated but are stressful.

Bell (see footnote 1) stated that, in general, all cold water fish cease growth at temperatures above 20.3°C because of increased metabolic activity. Fall chinook fingerlings had increasing percentage weight gains as temperature was increased from 10.0° to 15.7°C, and then weight decreased with a further increase in temperature to 18.4°C (Burrows in Bell, see footnote 1). Baldwin (1956) noted a similar relation for brook trout, with increases in percentage weight gain with increased temperature from 9.1° to 13.1°C and a subsequent decrease in percentage weight gain with temperatures exceeding 17.1°C. At 17.1°C, brook trout feeding decreased and, when temperature reached 21.2°C, the fish only ate 0.85 percent of their body weight per day. By comparison, a 100-mm-long salmonid that weighs 10 g would need to eat about 1.8 percent of its body weight each day to maintain itself and 2.5 percent to grow rapidly in 15°C water.

Salmonids prefer a rather narrow range of temperature in which to live (table 11), and temperature may help regulate density. In laboratory stream channels, Hahn (1977) found twice as many steelhead fry remained in channels with daily fluctuating (8°-19°C) or constant 13.5°C water temperatures than in a channel with constant 18.5°C water. Fry density in a channel with constant 8.5°C water was double that in channels with constant 13.5°C or fluctuating temperatures. Water temperatures in a particular stream vary seasonally, temporally, and spatially (for example, between forested and nonforested areas). Seasonal and temporal changes are largely out of human control; certain land-use practices (for example, channelization or removal of shade trees), however, can change the temperature in sections of streams. If riparian vegetation is removed, exposing the stream to direct sunlight, water temperatures usually increase in summer (Greene 1950,

Table 11—Preferred, optimum, and upper lethal temperatures of various salmonids [1/] (from Bell 1973 unless otherwise noted)

Species	Preferred temperature range	Optimum temperature	Upper lethal temperature
	----------°C----------		
Chinook	7.3-14.6	[2/]12.2	25.2
Coho	11.8-14.6	[3/]20.0	25.8
Chum	11.2-14.6	[4/]13.5	25.8
Pink	5.6-14.6	[3/]10.1	25.8
Sockeye	11.2-14.6	[3/]15.0	24.6
Steelhead	7.3-14.6	10.1	24.1
Cutthroat	9.5-12.9	--	23.0
Brown	3.9-21.3	--	24.1

1/ From Bell (see text footnote 1).
2/ From an unpublished report, "Fish health and Management: concept and methods of aquaculture," by G. W. Klontz, Univ. Idaho, Moscow, 1976.
3/ From Brett et al. (1958).
4/ From Garside and Tait (1958).

Chapman 1962, Gray and Edington 1969, Meehan 1970, Narver 1972, Moring and Lantz 1974, Moring 1975). Colder winter temperatures may result from loss of canopy and adversely affect egg incubation (Greene 1950, Chapman 1962).

DISSOLVED OXYGEN

The concentration of dissolved oxygen in streams is important to salmonids during rearing. At temperatures above 15°C, concentrations of dissolved oxygen regulate the rate of active metabolism of juvenile sockeye salmon (see footnote 1). Fry (1957) proposed that where the oxygen content became unsuitable, the active metabolic rate decreased. Rainbow trout swimming speeds were reduced 30 and 43 percent when oxygen was reduced to 50 percent of saturation at temperatures of 21°-23°C and 8°-10°C, respectively (Jones 1971). Growth rate, food consumption rate, and the efficiency of food utilization of juvenile coho salmon all declined when oxygen was 4 or 5 mg/l (Herrmann et al. 1962, and figs. 21, 22, and 23).

Juvenile chinook salmon avoided water with oxygen concentrations near 1.5-4.5 mg/l in the summer, but reacted less to low levels in the fall when temperatures were lower (Whitmore et al. 1960).

In a review paper, Davis (1975) examined information on incipient oxygen response thresholds for salmonids (table 12), and developed oxygen criteria with three concentrations (table 13). At the highest concentration, fish had ample oxygen and could function without impairment. At the middle concentration, the average member of a species begins to exhibit symptoms of oxygen

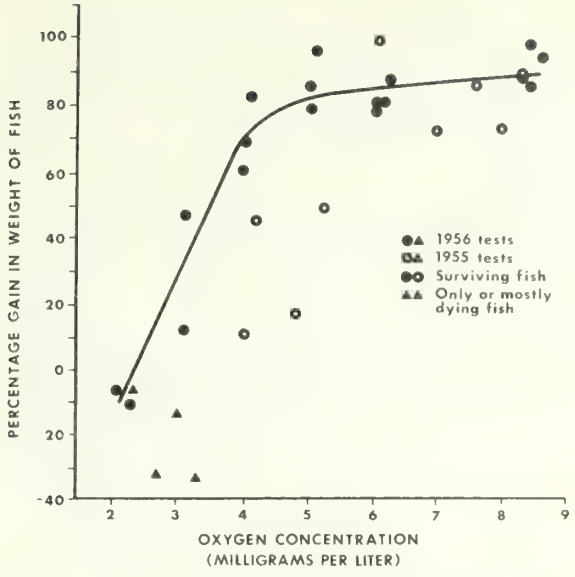


Figure 21—Weight gains (or losses) in 19 to 28 days among frequently fed age-class 0 coho salmon, expressed as percentages of the initial weight of the fish, in relation to dissolved oxygen concentration. The curve has been fitted to only the results of tests performed in 1956. All of the 1956 positive weight-gain values are results of 21-day tests (from Herrmann et al. 1962).

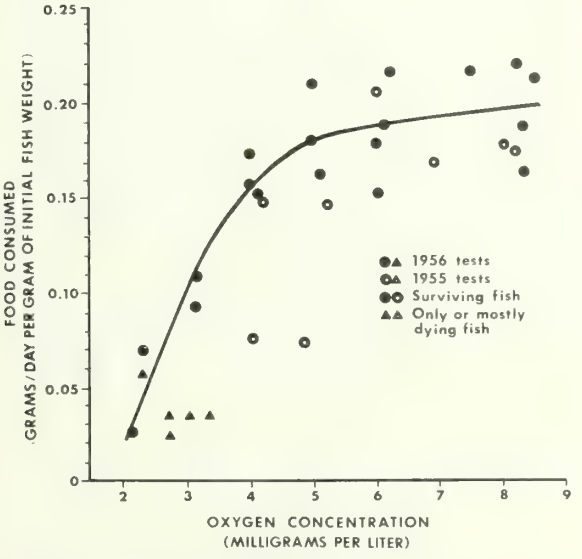


Figure 22—Grams of food (beach hoppers) consumed by frequently fed age-class 0 salmon per day per gram of initial weight of the fish, in relation to dissolved oxygen concentration. The curve has been fitted to only the 1956 data (from Herrmann et al. 1962).

distress; at the lowest concentration, a large portion of the fish population may be affected.

Dissolved oxygen concentrations are normally near

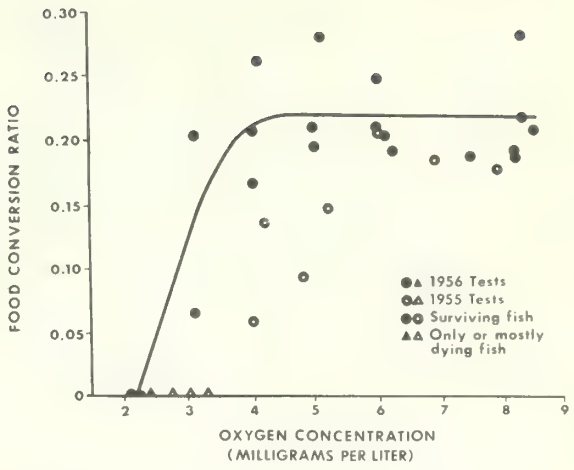


Figure 23—Food conversion ratios for frequently fed age-class 0 coho salmon, or their weight gains in grams per gram of food (beach hoppers) consumed, in relation to dissolved oxygen concentration. A food conversion ratio of zero (not a ratio having a negative value) has been assigned to each group of fish that lost weight. The curve has been fitted only to the 1956 data (from Herrmann et al. 1962).

saturation, except in small streams with large amounts of debris from logging or other sources (Hall and Lantz 1969) or in larger, slow-moving streams receiving large amounts of municipal or industrial waste.

SUSPENDED AND DEPOSITED SEDIMENT

Suspended and deposited fine sediment can adversely affect salmonid rearing habitat if present in excessive amounts. High levels of suspended solids may abrade and clog fish gills, reduce feeding, and cause fish to avoid some areas (Trautman 1933, Pautzke 1938, Smith 1939, Kemp 1949, Wallen 1951, Cooper 1956, Bachman 1958, Cordone and Kelley 1961). According to Bell (see footnote 1), streams with silt loads averaging less than 25 mg/l can be expected to support good freshwater fisheries. State turbidity standards for Colorado, Wyoming, Montana, and Oregon are set at no more

Table 12—Incipient oxygen response thresholds for various salmonids (modified from Davis 1975)[1/]

Species	Source	Size	Temperature	Dissolved oxygen		Response
				Concentration	Saturation	
			°C	Mg/l	Percent	
Arctic char	Holeton (1973)	--	2 + 0.05	2.18	15.8	Signs of asphixia and loss of equilibrium
Brown trout	Irving et al. (1941)	682-1 136 g	20	4.59	50	Blood not fully saturated with O_2 below this level
Brook trout	Irving et al. (1941)	682-1 136 g	20	4.59	50	" " "
	Graham (1949)	17-65 g	5	8.09	63.2	Onset of O_2-dependent metabolism
	"	17.65 g	8	5.99	50.7	Reduced cruising speed
	"	17-65 g	20	9.06	98.8	Onset of O_2-dependent metabolism
	" "	17-65 g	5-20	9.6-6.88	75	Reduced activity all temperatures
	Beamish (1964)	56-140 g	10, 15	5.75-5.18	50.7-51.0	Standard oxygen uptake reduced below this level
Rainbow trout	Irving et al. (1941)	682-1 136 g	20	4.59	50	Below this level, blood is not fully saturated with oxygen
	Randall and Smith (1967)	120-250 g	8.5-15	5.18-7.34	50.7-63.7	Circulatory changes occur, including a slowing of the heart
	Downing (1954)	13.3 ± 1.4 cm	17 ± .5	9.74	100	Any reduction in oxygen led to more rapid death in cyanide
	Jones (1971)	20 mo. old	8-10	5.94-5.67	50	43 percent reduction in maximum swimming speed
	" "	20 mo. old	21-23	4.50-4.34	50	30 percent reduction in maximum swimming speed
	Itazawa (1970)	235-510 g	2.3-13	8.73-6.74	63.1-63.6	Blood not fully saturated with O_2 below this level
	Kutty (1968)	--	15	5.08	50	Altered respiratory quotient, little capacity for anaerobic metabolism below this level
	Randall and Smith (1967)	--	15	5.18-6.47	51.0-63.7	Changes in oxygen transfer factor and effectiveness of O_2 exchange occur
Rainbow trout	Hughes and Saunders (1970)	400-600 g	13.5	5.35	51.0	Breathing amplitude and buccal pressure elevated
	Cameron (1971)	300 g	10, 15, 20	4.71-5.75	50.7-51.3	Blood not fully saturated with O_2 below this level
	Lloyd (1961)	1-11 g	17.5	5.78	60	Toxicity of zinc, lead, copper, phenols increased markedly below this level
Sockeye salmon	Brett (1964)	50 g	20-24	9.17-8.53	100	Available oxygen level appears to limit active metabolism and maximum swimming speed
	Davis (1973)	1 579 g	13	6.74	63.6	Blood not fully saturated with O_2 below this level
	Randall and Smith (1967)	1.5-1.7 kg	15	5.07	50	Elevated blood and buccal pressure, breathing rate increased
Coho salmon	Whitmore et al. (1960)	6.3-11 cm	--	4.5	--	Erratic avoidance behavior
	Hicks and DeWitt (1971)	5.1-14.8 cm	12 ± 1	9.0	83.1	Acute mortality in kraft pulpmill effluent increased below this level
	Davis et al. (1963)	Juvenile	10-20	11.33-9.17	100	Reduction of O_2 below saturation produced some lowering of maximum sustained swimming speed
	Dahlberg et al. (1968)	"	20	9.17	100	" " "
	Herrmann (1958)	"	"	8.0-4.0	87.2-43.6	Growth rate proportional to oxygen level with best growth at 8.0 mg/l, lowest at 4.0 mg/l
Chinook salmon	Whitmore et al. (1960)	6.3-11 cm	summer temp.	4.5		Marked avoidance of this level in summer
	" "	6.3-11 cm	fall temp.	4.5		Little avoidance of this level in fall
	Davis et al. (1963)	Juvenile	10-20	11.33-9.17	100	Reduction of O_2 below saturation lowered maximal sustained swimming speed
Atlantic salmon	Kutty and Saunders (1973)	87-135 g	15	4.5	44-33	Salmon stop swimming at a speed of 55 cm/s at O_2 levels below this; faster swimming requires more oxygen

[1] Courtesy of the Journal of the Fisheries Research Board of Canada.

Table 13—Response of freshwater salmonid populations to three concentrations of dissolved oxygen (modified from Davis 1975, courtesy of the Journal of the Fisheries Research Board of Canada)

Response	Oxygen	Saturation at given temperatures (°C)					
		0	5	10	15	20	25
	Mg/l	----------Percent----------					
Function without impairment	7.75	76	76	76	76	85	93
Initial distress symptoms	6.00	57	57	57	59	65	72
Most fish affected by lack of oxygen	4.25	38	38	38	42	46	51

than 10 JTU, 10 NTU, 5 JTU and 5 NTU over background levels, respectively.[6/]

Cordone and Kelley (1961) suggest that indirect rather than direct effects of too much fine sediment damage fish populations. Indirect damage to the fish population by destruction of the food supply, lowered egg or alevin survival, or changes in rearing habitat probably occurs long before the adult fish would be directly harmed (Ellis 1936, Corfitzen,[7/], Sumner and Smith,[8/] Tebo 1955, 1957, 1974, Tarzwell 1957, Ziebell 1957, Casey,[9/] Bartsch 1960, Cordone and Pennoyer,[10/] Chapman 1962, Bjornn et al. 1977).

[6/] JTU = Jackson turbidity units. NTU = Nephelometric turbidity units.

[7/] Unpublished mimeographed report, "A study of the effect of silt on absorbing light which promotes the growth of algae and moss in canals," by W. D. Corfitzen. U.S. Dep. Int., Bur. Reclam., 1939.

[8/] Unpublished mimeographed report, "A biological study of the effects of mining debris dams and hydraulic mining on fish life in the Yuba and American Rivers in California," by F. H. Sumner and O. R. Smith. Submitted to the U.S. District, Eng. Office, Sacramento, California, from Stanford Univ., 1939.

[9/] Unpublished mimeographed report, "The effects of placer mining (dredging) on a trout stream," by O. E. Casey. Annu. Prog. Rep., Proj. F-34-R-1. Water Quality Investigations, Federal Aid in Fish Restoration, Idaho Dep. Fish and Game, Boise, 1959.

[10/] Unpublished mimeographed report, " Notes on silt pollution in the Truckee River drainage," by A. J. Cordone and S. Pennoyer. Calif. Dep. Fish and Game: Inland Fish Admin. Rep., Sacramento, 1960.

Deposited sediment may reduce available summer rearing (fig. 24) and winter holding (fig. 25) habitat for fish (Stuehrenberg 1975, Klamt 1976, Bjornn et al. 1977). Bjornn et al. (1977) added fine sediment (less than 6.4 mm in diameter) to natural stream channels and found juvenile salmon abundance decreased in almost direct proportion to the amount of pool volume lost to fine sediment (fig. 26). Because sediment budgets are difficult to determine for each stream, Bjornn et al. recommended using the percentage of fine sediment in selected riffle areas as an index of the "sediment health" of streams. They reasoned that if the riffles contained negligible amounts of fine sediment, then the pools and interstitial spaces between the boulders of the stream substrate would also have negligible amounts of sediment.

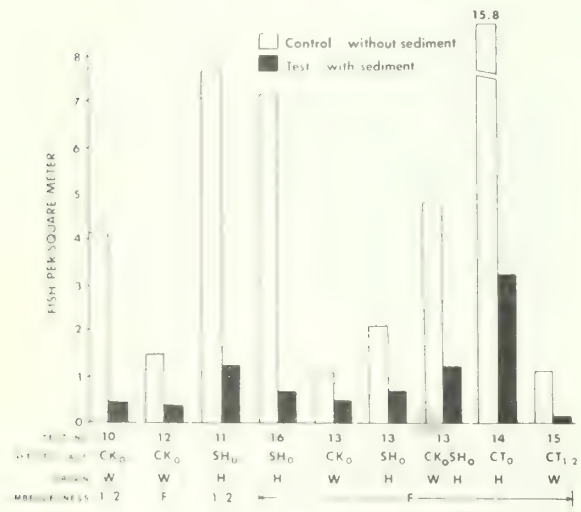


Figure 24—Densities of fish remaining in artificial stream channels after 5 days during winter tests, 1975: W = wild; H = hatchery; ½ = boulders in pools ½ imbedded with sediment; F = fully imbedded; CK_0 = age 0 chinook salmon, SH_0 = age 0 steelhead trout; CT_0 = age 0 cutthroat trout, $CT_{1,2}$ = age 1 cutthroat trout (from Bjornn et al. 1977).

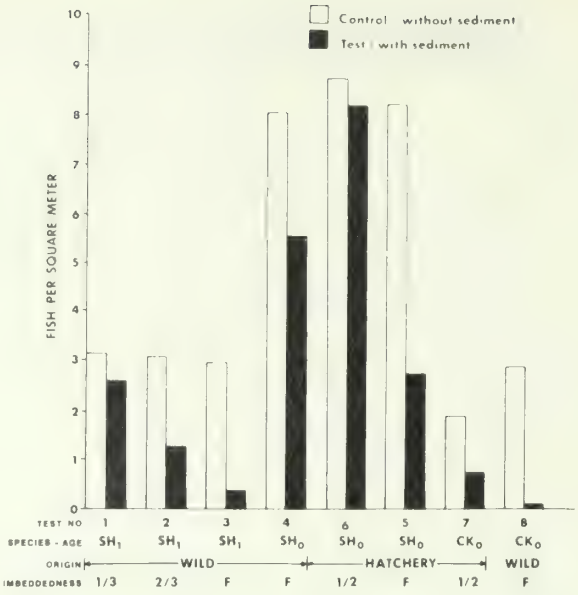


Figure 25—Densities of fish remaining in the Hayden Creek artificial stream channels after 5 days during the summer tests, 1974 and 1975: SH_1 = age 1 steelhead; CK_0 age 0 chinook; ⅓ = key boulders in pools ⅓ imbedded with sediment; F = key boulders in pools fully imbedded (from Bjornn et al. 1977).

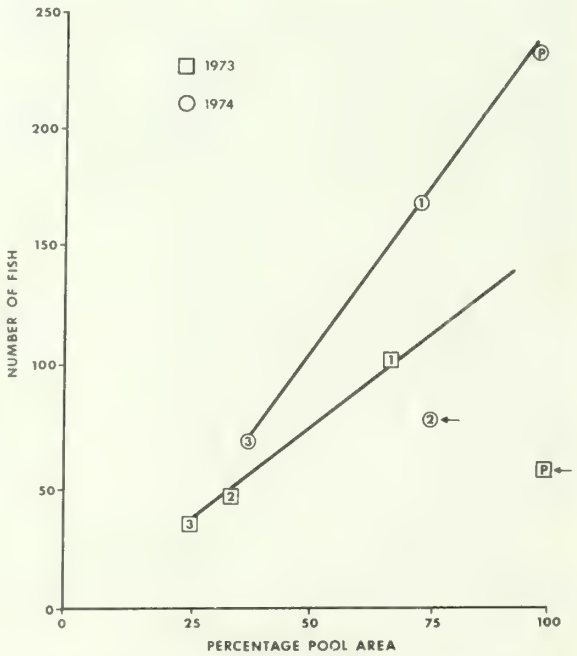


Figure 26—Fish numbers in upper test pool versus percentage pool area deeper than 0.30 m, during the sediment additions into Knapp Creek, 1973 and 1974. Arrows denote observations not used in fitting the regression line. P = prior to addition of sediment; 1 = after first addition; 2 = after second addition; 3 = after third addition (from Bjornn et al. 1977).

COVER

Cover is perhaps more important to anadromous salmonids during rearing than at any other time, for this is when they are most susceptible to predation from other fish and terrestrial animals. Cover needs of mixed populations of salmonids are not easily determined (Giger 1973). Shelter needs may vary diurnally (Kalleberg 1958, Edmundson et al. 1968, Allen 1969, Chapman and Bjornn 1969), seasonally (Hartman 1963, 1965, Chapman 1966, Chapman and Bjornn, 1969), by species (Hartman 1965, Ruggles 1966, Allen 1969, Chapman and Bjornn 1969, Lewis 1969, Pearson et al. (see footnote 4), Wesche 1973, Hanson 1977), and by fish size (Butler and Hawthorne 1968, Allen 1969, Chapman and Bjornn 1969, Everest 1969, Wesche 1973, Hanson 1977).

Overhead cover--riparian vegetation, turbulent water, logs, or undercut banks--is used by most salmonids (Newman 1956, Wickham 1967, Butler and Hawthorne 1968, Baldes and Vincent 1969, Bjornn 1969, Chapman and Bjornn 1969, Lewis 1969, Lister and Genoe 1970, Wesche 1973). Beside providing shelter from predators, overhead cover produces areas of shade near stream margins. These areas are the preferred habitat of many juvenile salmonids (Hartman 1965, Chapman 1966, Allen 1969, Everest 1969, Mundie 1969, Everest and Chapman 1972).

Submerged cover--large rocks in the substrate, aquatic vegetation, logs, and so on--is also used by rearing salmonids. Hoar et al. (1957) and Hartman (1965) observed that newly emerged salmonids tend to hide under stones. Similar behavior is typical of overwintering juvenile steelhead and chinook that seek refuge within rock and rubble substrate in Idaho streams (Chapman 1966, Chapman and Bjornn 1969, Everest 1969, Morrill and Bjornn 1972).

The relative importance of cover is illustrated by experiments in which salmonid abundance declined when cover was reduced (Boussu 1954, Peters and Alvord 1964, Elser 1968) and in experiments where salmonid abundance increased when cover was added to a stream (Tarzwell 1937, 1938, Shetter et al. 1946, Warner and Porter 1960, Saunders and Smith 1962, Chapman and Bjornn 1969, Hunt 1969, 1976, Hahn 1977, Hanson 1977).

STREAMFLOW

Recommended streamflows for rearing habitat have usually been based on the individual components (such as food, cover) of habitat rather than numbers or biomass of fish. Thompson (1972) listed guidelines for developing streamflow recommendations in rearing habitat:

- adequate depth over riffles
- riffle/pool ratio near 50:50
- approximately 60 percent of riffle area covered by flow
- riffle velocities of 0.31-0.46 m/s
- pool velocities of 0.09-0.24 m/s
- stream cover available as shelter for fish.

Such guidelines are obviously based on the food production, cover, and microhabitat needs of fish, rather than the relation between streamflow and fish production.

Streamflow has been related to cover (Kraft 1968, 1972, Wesche 1973, 1974, and figs. 27, 28, and 29); streamflow and pool area to standing crop of fish (Kraft 1968, 1972, Nickelson and Reisenbichler 1977, and fig. 30); standing crop to cover (Wesche 1974, Nickelson and Reisenbichler 1977, and figs. 31 and 32); and standing crop to a habitat quality index (Nickelson 1976, and fig. 33). Such studies suggest a definite relation between stream carrying capacity for fish and discharge.

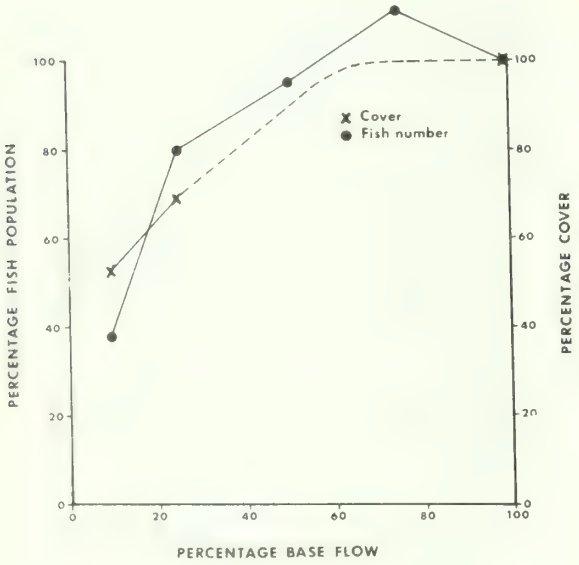


Figure 27—Comparison of percentage reductions of fish numbers and cover in three runs in Blacktail Creek, Montana (data from Kraft 1968, from White 1976).

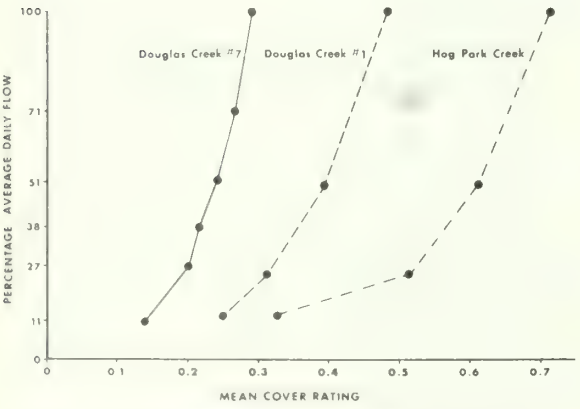


Figure 28—Changes observed in the mean trout-cover rating as flow was reduced at the Douglas Creek No. 1, 7, and Hog Park Creek study areas (from Wesche 1974).

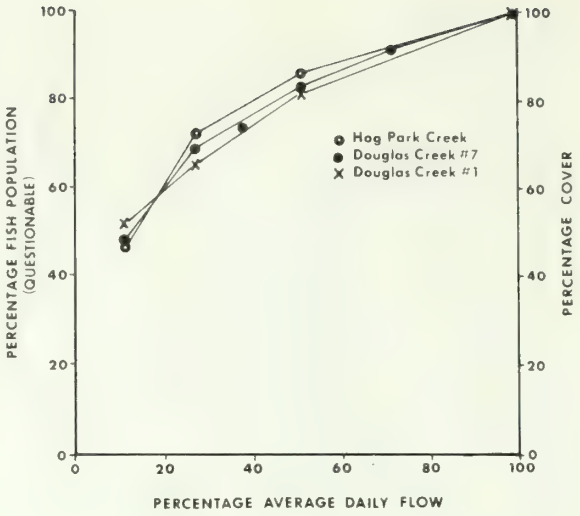


Figure 29—Comparison of percentage of habitat reduction with percentage decrease in average daily flow and hypothetical percentage decrease in fish population (data from Wesche 1974, from White 1976).

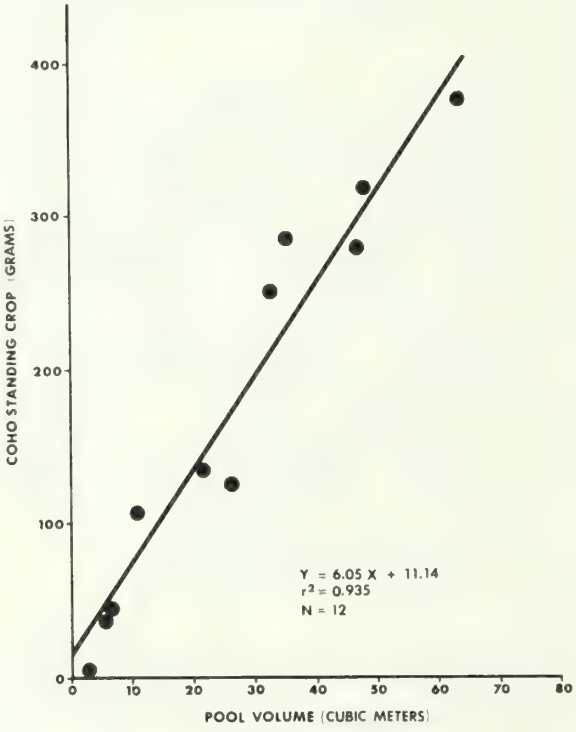


Figure 30—Relation between pool volume and juvenile coho standing crop (from Nickelson and Hafele 1978).

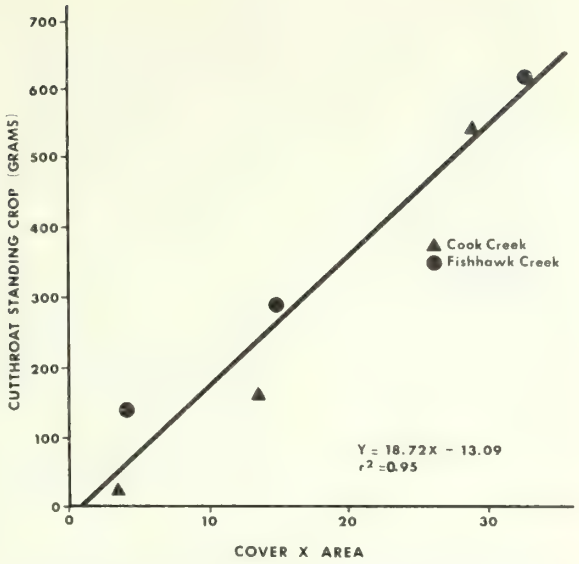


Figure 31—Relation between mean trout cover ratings and standing crop estimates of trout at eleven study areas (from Wesche 1974).

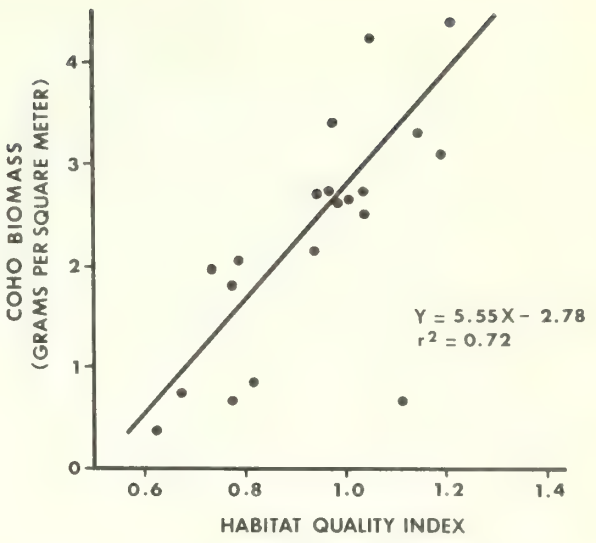


Figure 33—Relation between a habitat quality index and coho salmon biomass in six Elk Creek study sections at flows of 3.00, 2.25, and 1.50 ft³/s (from Nickelson 1976).

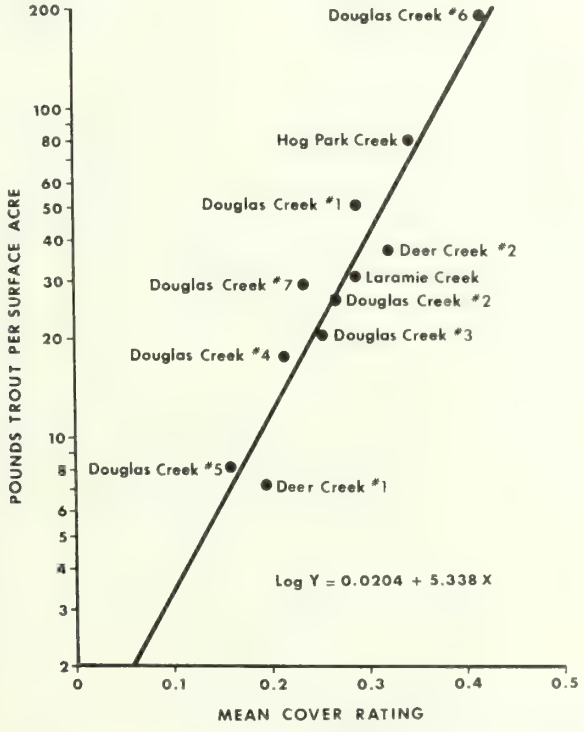


Figure 32—Relation between cover times area and cutthroat trout standing crop in two Oregon coastal streams (from Nickelson and Reisenbichler 1977).

SPACE

Space requirements of juvenile salmonids in streams vary with species, age, and time of the year and are probably related to abundance of food (Chapman 1966). The interactions and relation between cover, food abundance, and microhabitat preferences of the various species of salmonids are not well understood; until they are, spatial needs of the fish will be less than adequately defined.

From measurements of fish densities in streams, we have some idea of spatial requirements of juvenile salmonids. Pearson et al. (see footnote 4) Nickelson and Reisenbichler (1977), and Nickelson and Hafele (1978, and fig. 30) found that coho standing crop was directly related to pool volume. Bjornn et al. (1977) found a similar relation for chinook salmon in small streams (fig. 26). Pearson et al. found a close relation between total stream area and coho numbers--perhaps

an example of the idea that more space equals more food equals more fish. Food and space are thought to be the most important factors influencing fish density in streams (Larkin 1956, Chapman 1966). Studies in California by Burns (1971) revealed significant correlations between living space and salmonid.biomass; decreased living space resulted in increased fish mortality. Not surprisingly, the highest mortality was associated with the summer low flow period. The studies of Kraft (1968, 1972 and fig. 27) and Wesche (1974, and fig. 29) lend support to the concept that reductions in discharge decrease living space and thus decrease numbers and biomass of salmonids.

Changes in streamflow influence velocities and area of riffles more than area of pools. Giger (1973) suggested that if set spatial demands are the primary regulators of fish density in pools, then increasing the flow in streams may not lead to increased abundance. He accepts the logic of Chapman's (1965) idea that spatial requirements of fish control their density below ceilings set by the supply of food. Chapman (1966) suggested that salmonids have a minimum spatial requirement that has been fixed over time by the minimum food supply.

Space needed by fish increases with age and size. Allen (1969) assembled data on densities of salmonids in streams and found positive correlations between area per fish and age or length (figs. 34 and 35). Additional data on densities of salmon and trout with age, size, and locality are presented in table 14 and figure 36. Allen concluded from the data he examined that densities of 10-cm salmonids averaged about 0.17 fish/m^2 (1.7 g/m^2).

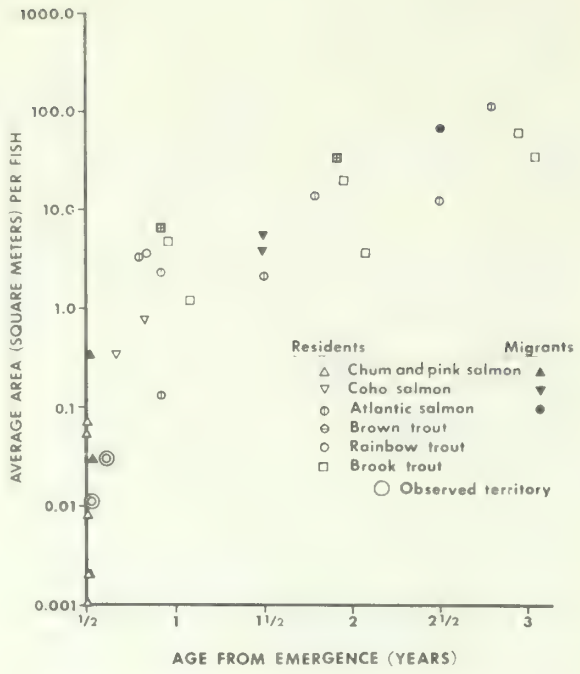


Figure 34—Average area per fish (on a logarithmic scale) against age (from Allen 1969).

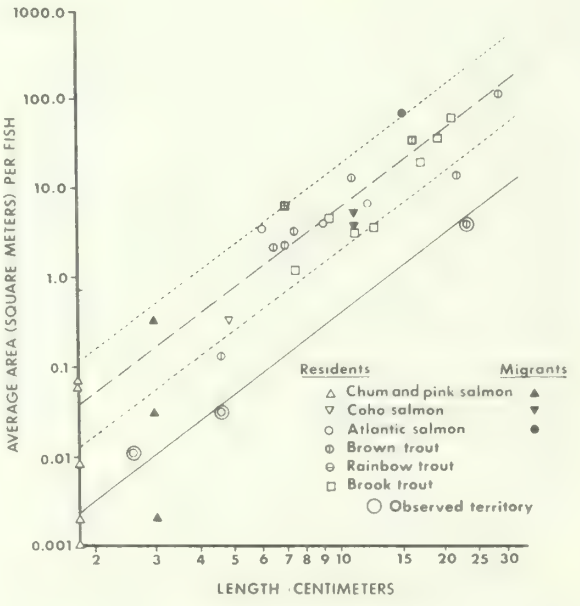


Figure 35—Average area per fish against length on logarithmic scales (from Allen 1969).

Table 14—Densities of salmon and trout in streams

Species	Age/ size	Area/ fish	Fish/ area	Weight/area	Stream size or flow rate	Comments	Reference
	Yr/cm	M^2	M^2	G/m^2			
Pink salmon	egg-alevin	0.001	1000	--	--	B.C.	Hunter (1959)
	" "	.070	14.3	--	--	Washington	Bliss and Heiser (1967)
	" "	.002	500	--	--	Alaska	Hoffman (1965)
	" "	.008	125	--	--		"
	0+/2	.03	33.3	--	--	B.C.	Hunter (1959)
	0+/2	.002	500	--	--	Alaska	Merrell (1962)
	0+/2	.33	3.0	--	--	B.C.	Wickett (1958)
Chum salmon	egg-alevin	.001	1000	--	--	B.C.	Hunter (1959)
	" "	.056	17.9	--	--	Washington	Bliss and Heiser (1967)
	0+/2	.03	33.3	--	--	B.C.	Hunter (1959)
Coho salmon	0+/2	.33	3.0	--	--	B.C.	Wickett (1958)
	alevin			5-12	--	Oregon	Chapman (1965)
	I+	2.4 (2.94-2.00)	.42 (.34-.50)	2-4		Oregon	Chapman (1965)
	"	3.7	.3	--	--	B.C.	Hunter (1959)
	"	5.5	.2	--	--	B.C.	Wickett (1951)
	"	2.9 (1.92-4.28)	.37 (.26-.52)	--	Avg. flows: range, 41.6-183 ft^3	Oregon	Hall and Lantz (1969)
Chinook salmon	0+	.74	1.35	12.9	Median 4-5 m	Idaho, est. of	Bjornn (1978)
	"	1.69	.59	5.4	6-10 m	summer rearing capacity	"
	"	(.59-3.301)	(1.70-.30)	(6.4-.86)	Flows range 0.107-1.3 m^3/s	4 streams in Idaho	Sekulich and Bjornn (1977)
	"	(.94-2.27)	(1.06-.44)	(4.4-1.01)	"		"
	"	.53	1.90	--	--	Idaho	Bjornn et al. (1977)
Chinook salmon	I+	3.33	.30	--	--	4 streams in Idaho	Bjornn et al. (1974)
Steelhead trout	0+	.93	1.08	6.1	Medium, width about 4-5 m	Idaho, est. of	Bjornn (1978)
	0+	1.43	.70	3.2	" "	summer rearing	" "
	0+	1.92	.52	3.0	Medium, width about 6-10 m	capacity	" "
	I+	16.67	.06	4.3	Medium, 4-5 m	"	" "
	I+	33.33	.03	1.9	" "	" "	" "
	I+	5.88	.17	13.0	Medium, 6-10 m	"	" "
	0+	.59	1.70	(4.4-1.01)	Flows range 0.107-1.3 m^3/s	4 streams in Idaho	Bjornn et al. (1974)
	I+	6.67	.15	" "	--	" "	" "
	0+	3.88	.258	" "	Small	" "	Hanson (1977)
	I+	16.39	.061	--	"	"	"
	II+	17.24	.058	--	"	"	"
	0+	4.35	.23	--	Medium	" "	" "
	I+	14.49	.069	--	"	" "	" "
	II+	19.61	.051	--	"	" "	" "
	II+	26.14 (m/fish)	.038 (fish/m)	--	Large (Lochsa River)	Idaho average densities for three sections; low densities result from low spawning escapements	Graham (1977)

Table 14—Densities of salmon and trout in streams —(Continued)

Species	Age/ size	Area/ fish	Fish/ area	Weight/area	Stream size or flow rate	Comments	Reference
	Yr/cm	M^2	M^2	G/m^2			
Steelhead salmon	I+	109.89 (m/fish)	0.009 (fish/m)	--	Large (Lochsa River)	(cont. from previous page)	Graham 1977
	I+	60.06 (m/fish)	.017 (fish/m)	--	Large (Selway River)	" " "	"
	II+	23.47 (m/fish)	.043 (fish/m)	--	" "	" "	"
	I+	17.84	.056	--	Small tributaries	Idaho, trib. of Lochsa R.	" "
	II+	14.22	.070	--	" "	" "	" "
	I+	32.15	.031	--	" "	Idaho, trib. of Selway R.	" "
	II+	18.12	.055	--	" "	" "	" "
	I+	1.43-1.25	(.7-.8)	--	Small	Idaho, densities are those present in the fall after stocking in early spring	" "
	0+	52.23 (m/fish)	.019 (fish/m)	-	Large (Lochsa River)	Idaho, avg. density for	" "
	0+	204.08 (m/fish)	.0049 (fish/m)	--	" "	3 sections	" "
	0+	22.75	.439	--	Small (trib. streams)	" "	" "
	0+	88.11	.111	--	" "	" "	" "
	0+	.97	1.03	3.69	Flow - 0.27--.56 cms during July-August	Densities are those present in the fall after stocking in early spring	" "
	0+	1.07	.94	6.64	Flow - 0.59-0.95 cms	" "	" "
Atlantic salmon	0+	5.00	.2	2.70	Small streams	Scotland, densities are	Mills (1969)
	0+	1.08	.93	2.94		those present in the fall	" "
	0+	1.25	.80	4.25	" "	after stocking in early	" "
	0+	2.78	.36	2.81	" "	spring	" "
	0+	2.56	.39	2.83	" "	" "	" "
	0+	5.56	.18	1.17	" "	" "	" "
	0+	9.09	.11	.96	Small streams	Scotland, densities are	Mills (1969)
	0+	1.64	.61	1.04	" "	those present in the fall	" "
	0+	6.67	.15	1.18	" "	after stocking in early	" "
	0+	4.55	.22	1.34	" "	spring	" "
	0+	2.56	.39	1.66	" "	" "	" "
	0+	14.29	.07	1.27	" "	" "	" "
	0+	6.25	.16	1.09	" "	" "	" "
	0+	1.85	.54	1.95	" "	" "	" "
	0+	6.67	.15	1.93	" "	" "	" "
Brown trout	0+	.53	1.9	1.6	Mean width 0.9 m	England, small, headwater	LeCren (1969)
	0+	1.67	.6	1.1	2.2 m	streams	" "
	0+	5.00	.2	.2	3.0 m	" "	" "
	0+	5.00	.2	.3	" 3.7 m	" "	" "
	0+	1.0	1.0	2.8	" 2.5 m	" "	" "
	0+	.42	2.4	--	" 6.6 m	" "	" "
	I+	2.00	.5	3.7	" .9 m	" "	" "
	I+	5.00	.2	1.9	" 2.2 m	" "	" "
	I+	5.00	.2	1.1	" 3.0 m	" "	" "
	I+	10.0	.1	1.0	" 3.7 m	" "	" "
	I+	10.0	.1	2.9	" 2.5 m	" "	" "
	I+	5.00	.2	--	" 6.6 m	" "	" "
	2.6-6.5 cm	4.55	0.22	--	Small, widths range 0.6-	Densities are averages of	Mills (1969)
	6.6-10.5 cm	3.13	.32	--	1.5 m, avg. 1.0 m	4 stream sections	" "
	10.6-14.5 cm	7.69	.13	--	" "	" "	" "
	14.6-18.5 cm	16.67	6.06	--	" "	Scotland	" "
	0+/4.5	.13	7.69		" "	England	LeCren (1965)
	I+/6.5	2.20	.45	--	" "	England	Horton 1961
	0+/7	2.30	.43	--	" "	California	Needham, et al. (1945)
	0+/7.5	1.20	.83	--	" "	New Zealand	Allen (1951)
	II+/11	13.0	.77	--	" "	England	Horton (1961)
	I+/22	14.0	.071	--	" "	New Zealand	Allen (1951)
	II+/28	120.0	.008	--	" "	New Zealand	Allen (1951)

Densities of age-0 trout and salmon at the end of their first summer (70-120 mm in length) average about 5 m^2 of stream per fish (mode about 2 m^2). After 2 years of rearing, densities averaged 2-16 m^2/fish, and for larger fish, 15-27 m^2/fish (fig. 36). The spread in densities portrayed in figure 36 results partly from differences in natural or artificial stocking rates, size of stream, and habitat quality.

Juvenile salmonids usually occupy sites in streams referred to as "focal points" from which they venture out to perform other functions (Wickham 1967). Characteristics of these focal points in water velocities, water depths, substrate, and cover represent the microhabitat preferences of the fish (table 15) to remain oriented into the

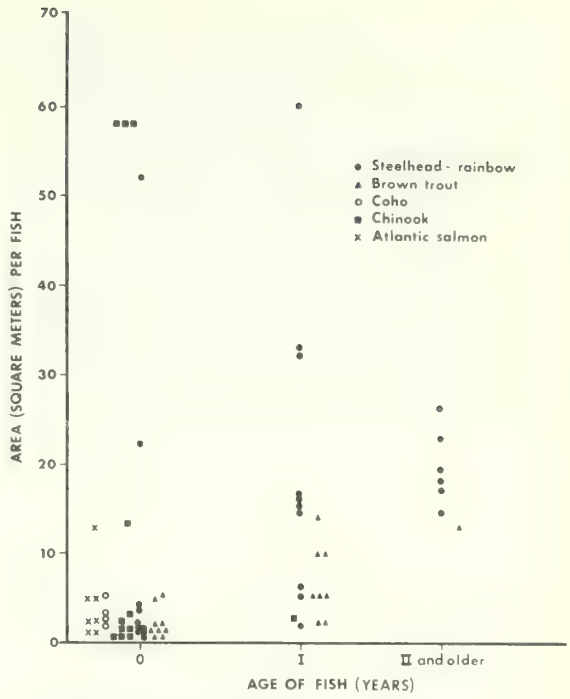


Figure 36—Densities of age 0, I, II, and older salmon and trout in streams usually after 1, 2, 3, or more summers of growth, respectively (see table 14 for sources of data).

Table 15—Depth, velocity, and substrate microhabitat preferences of salmonids in streams

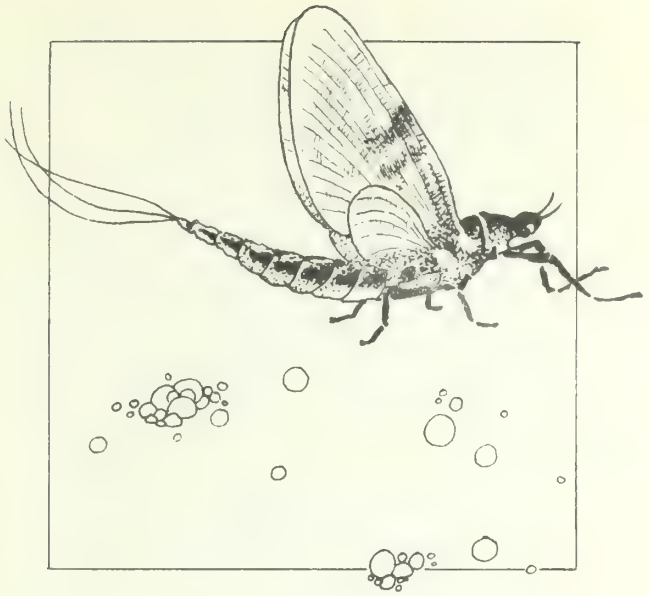
Species	Reference	Age	Depth	Velocity	Substrate
			M	M/s	Cm
Steelhead	Everest and Chapman (1972)	0	<0.15	<0.15	Rubble
	" "	1	.60-.75	.15-.30	Rubble
	Hanson (1977)	1	.51 mean	.10 mean	10-30
	" "	2	.58 "	.15 "	10-30
	" "	3	.60 "	.15 "	10-30
	Stuehrenberg (1975)	0	<.30	.14 (range .03-.26)	--
	" "	1	>.15	.16 (range .05-.37)	--
	Thompson (1972)	0	.18-.67	.6-.49	--
Chinook	Everest and Chapman (1972)	0	.15-.30	<.15	Silt
	Stuehrenberg (1975)	0	<.61	.09 (range .0-.21)	-
	" "	1	<.61	.17 (range .05-.38)	--
	Thompson (1972)	0	.30-1.22	.06-.24	--
Coho	Pearson et al.[1/]	0	--	.09-.21	--
	Thompson (1972)	0	.30-1.22	.05-.24	--
	Nickelson and Reisenbichler (1977)	0	>.30	<.30	--
Cutthroat	Thompson (1972)	0, 1	.40-1.22	.6-.49	--
	Hanson (1977)	1	.51 mean	.10 mean	5-20
	" "	2	.56 "	.14 "	5-30
	" "	3	.57 "	.20	5-30
	" "	4	.54 "	.14 "	30

1/ See text footnote 4.

current (Baldes 1968). Habitat selected by fish is influenced by their ability and the availability of food (Kalleberg 1958, Mason and Chapman 1965, Chapman 1966, Chapman and Bjornn 1969, Everest and Chapman 1972).

In summary, good rearing habitat for anadromous salmonids consists of a mixture of pools and riffles, adequate cover, water temperatures that average between 10° and 15°C during the summer, dissolved oxygen usually at saturation, suspended sediment less than 25 mg/l, and riffles with less than 20 percent fine sediment (less than 6.4 mm in diameter). The optimum combination of stream areas used by aquatic invertebrates and all ages of fish cannot be described until the interrelations between the components are better understood.





LITERATURE CITED

Alderdice, D. F., W. P. Wickett, and J. R. Brett. 1958. Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. J. Fish. Res. Board Can. 15(2):229-250.

Allen, K. R. 1951. The Horokiwi Stream: A study of a trout population. N.Z. Mar. Dep. Fish. Bull. No. 10, Wellington. 231 p.

Allen, K. R. 1959. The distribution of stream bottom faunas. Proc. N.Z. Ecol. Soc. 6:5-8.

Allen, K. R. 1969. Limitations on production in salmonid populations in streams, p. 3-18. In T. G. Northcote (ed.), Symposium on Salmon and Trout in Streams. H. R. MacMillan Lectures in Fisheries, Univ. B.C., Vancouver.

Arthur, J. F. 1963. The relationship of water velocities to aquatic insect populations on the Kern River, Kern Co., Calif. Report for Independent Study 290, Dep. Biol. Fresno State Coll., Calif. Jan. 1963.

Bachman, R. W. 1958. The ecology of four north Idaho trout streams with reference to the influence of forest road construction. M.S. thesis, Univ. Idaho, Moscow. 97 p.

Baldes, R. J. 1968. Microhabitat velocity occupied by trout. M.S. thesis, Colo. State Univ., Fort Collins. 33 p.

Baldes, R. J., and R. E. Vincent. 1969. Physical parameters of microhabitats occupied by brown trout in an experimental flume. Trans. Am. Fish. Soc. 98(2):230-238.

Baldwin, N. S. 1956. Food consumption and growth of brook trout at different temperatures. Trans. Am. Fish. Soc. 86:323-328.

Bartsch, A. F. 1960. Settleable solids, turbidity, and light penetration as factors affecting water quality. Biological Problems in Water Pollution, Trans. 1959 Seminar. U.S. Dep. Health, Educ. and Welfare, Tech. Rep. W60-3, R. A. Taft Sanit. Eng. Cent. Cincinnati, Ohio.

Baxter, G. 1961. River utilization and the preservation of migratory fish life. Proc. Inst. Civ. Eng. 18:225-244.

Beamish, F. W. H. 1964. Respiration of fishes with special emphasis on standard oxygen consumption. II. Influence of weight and temperature on respiration of several species. Can. J. Zool. 42:177-188.

Bjornn, T. C. 1969. Embryo survival and emergence studies, Job. No. 5, Federal Aid in Fish and Wildlife Restoration. Job Completion Rep., Proj. F-49-R-7. Idaho Fish and Game Dep., Boise. 11 p.

Bjornn, T. C. 1978. Survival, production, and yield of trout and chinook salmon in the Lemhi River, Idaho. Bull. No. 27, Coll. of For., Wildl. and Range Sci., Univ. Idaho, Moscow. 57 p.

Bjornn, T. C. , M. A. Brusven, Myron Molnau, F. J. Watts, R. L. Wallace, D. R. Neilson, M. F. Sandien, and L. C. Stuehrenberg. 1974. Sediment in streams and its effects on aquatic life. Tech. Completion Rep. Water Resour. Res. Int. Proj. B-025-IDA. Univ. Idaho, Moscow. 27 p.

Bjornn, T. C., M. A. Brusven, M. P. Molnau, J. H. Milligan, R. A. Klamt, E. Chacho, and C. Schaye. 1977. Transport of granitic sediment in streams and its effects on insects and fish. For. Wildlife and Range Exp. Stn., Completion Rep. Water Resour. Res. Inst. Proj. B-036-IDA. Univ. Idaho, Moscow. 43 p.

Bliss, B., and D. Heiser. 1967. 1966 chum salmon hydraulic sampling. Wash. Dep. Fish Res. Div. Prog. Rep., Olympia. p. 8-16.

Boussu, M. F. 1954. Relationship between trout populations and cover on a small stream. J. Wildl. Manage. 18:227-239.

Bovee, K. D. 1974. The determination, assessment and design of "instream value" studies for the northern Great Plains region. Rep. for the Northern Great Plains Resour. Program. Denver, Colo. 205 p.

Brannon, E. L. 1965. The influence of physical factors on the development and weight of sockeye salmon embryos and alevins. Int. Pac. Salmon Fish. Comm. Prog. Rep. No. 12. 26 p.

Brett, J. R. 1952. Temperature tolerance in young Pacific salmon, genus Oncorhynchus sp. J. Fish. Res. Board Can. 9:265-323.

Brett, J. R. 1964. The respiratory metabolism and swimming performance of young sockeye salmon. J. Fish. Res. Board Can. 21:1183-1226.

Briggs, J. C. 1953. The behavior and reproduction of salmonid fishes in a small coastal stream. Calif. Dep. Fish and Game. Fish. Bull. 94. 62 p.

Burner, C. J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish and Wildl. Serv. Fish. Bull. 61(52):97-110.

Burns, J. W. 1971. The carrying capacity for juvenile salmonids in some northern California streams. Calif. Fish and Game 57(1):24-57.

Butler, R. L., and V. M. Hawthorne. 1968. The reactions of dominant trout to changes in overhead artificial cover. Trans. Am. Fish. Soc. 97(1):37-41.

Cameron, J. N. 1971. Oxygen dissociation characteristics of the blood of rainbow trout, Salmo gairdneri. Comp. Biochem. Physiol. 38:699-704.

Chapman, D. W. 1962. Effects of logging upon fish resources of the west coast. J. For. 60(8): 533-537.

Chapman, D. W. 1965. Net production of juvenile coho salmon in three Oregon streams. Trans. Am. Fish. Soc. 94(1):40-52.

Chapman, D. W. 1966. Food and space as regulators of salmonid populations in streams. Am. Nat. 100: 345-357.

Chapman, D. W., and T. C. Bjornn. 1969. Distribution of salmonids in streams, with special reference to food and feeding. p. 153-176. In T. G. Northcote (ed.), Symposium on Salmon and Trout in Streams. H. R. MacMillan Lectures in Fisheries, Univ. B.C., Vancouver.

Clay, C. H. 1961. Design of fishways and other fish facilities. Can. Dep. Fish., Ottawa. 301 p.

Coble, D. W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Trans. Am. Fish. Soc. 90(4):469-474.

Collings, M. R. 1972. A methodology for determining instream flow requirements for fish. Proceedings, Instream Flow Methodology Workshop. Wash. State Water Program, Olympia. p. 72-86.

Combs, B. D. 1965. Effect of temperature on the development of salmon eggs. Prog. Fish-Cult. 27(3):134-137.

Combs, B. D., and R. E. Burrows. 1957. Threshold temperatures for the normal development of chinook salmon eggs. Prog. Fish-Cult. 19(1):3-6.

Cooper, A. C. 1956. A study of the Horsefly River and the effect of placer mining operations on sockeye spawning grounds. Int. Pac. Salmon Fish. Comm. Publ. 3. 58 p.

Cooper, A. C. 1965. The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevins. Int. Pac. Salmon Fish. Comm. Bull. 18. 71 p.

Cope, O. B. 1957. The choice of spawning sites by cutthroat trout. Proc. Utah Acad. Sci., Arts, and Lett. 34:73-79.

Cordone, A. J., and D. W. Kelley. 1961. The influence of inorganic sediment on the aquatic life of streams. Calif. Fish and Game 47(2):189-228.

Corning, R. V. 1969. Water fluctuation, a detrimental influence on trout streams. Proc. 23rd Ann. Conf. Southeast. Assoc. Game and Fish Comm., p. 431-454.

Cummins, K. W. 1966. A review of stream ecology with special emphasis on organism-substrate relationships, p. 2-51. In K. W. Cummins, C. A. Tyron, Jr., and R. T. Hartman (eds.), Organism-Substrate Relationships in Streams, Spec. Publ. No. 4, Pymatuning Lab. of Ecology, Univ. Pittsburgh, Pa.

Dahlberg, M. L., D. L. Shumway, and P. Doudoroff. 1968. Influence of dissolved oxygen and carbon dioxide on swimming performance of largemouth bass and coho salmon. J. Fish. Res. Board Can. 25(1):49-70.

Davis, G. E., J. Foster, C. E. Warren, and P. Doudoroff. 1963. The influence of oxygen concentration on the swimming performance of juvenile Pacific salmon at various temperatures. Trans. Am. Fish. Soc. 92(2):111-124.

Davis, J. C. 1973. Sublethal effects of bleached kraft pulpmill effluent on respiration and circulation in sockeye salmon (Oncorhynchus nerka). J. Fish. Res. Board Can. 30(3):369-377.

Davis, J. C. 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: a review. J. Fish. Res. Board Can. 32(12):2295-2332.

Delisle, G. E., and B. E. Eliason. 1961. Stream flows required to maintain trout populations in the Middle Fork Feather River Canyon. Water Proj. Branch Rep. No. 2, Appendix, Calif. Dep. Fish and Game, Sacramento. 19 p.

Doudoroff, P., and C. E. Warren. 1965. Environmental requirements of fishes and wildlife--dissolved oxygen requirements of fishes. Spec. Rep. No. 141. Oreg. Agric. Exp. Stn., Corvallis.

Downing, K. M. 1954. The influence of dissolved oxygen concentration on the toxicity of potassium cyanide to rainbow trout. J. Exp. Biol. 31:161-164.

Edmundson, E., F. H. Everest, and D. W. Chapman. 1968. Permanence of station in juvenile chinook salmon and steelhead trout. J. Fish. Res. Board Can., 25(7): 1453-1464.

Eiserman, F., G. Dern, and J. Doyle. 1975. Coldwater stream handbook for Wyoming. USDA Soil Cons. Serv.

Ellis, M. M. 1936. Erosion silt as a factor in aquatic environments. Ecology 17(1):29-42.

Elser, A. A. 1968. Fish populations of a trout stream in relation to major habitat zones and channel alterations. Trans. Am. Fish. Soc. 97(4):389-397.

Everest, F. H. 1969. Habitat selection and spatial interaction of juvenile chinook salmon and steelhead trout in two Idaho streams. Ph.D. thesis, Univ. Idaho, Moscow. 77 p.

Everest, F. H., and D. W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. J. Fish. Res. Board Can. 29(1):91-100.

Fisher, S. G., and A. LaVoy. 1972. Difference in littoral fauna due to fluctuating water levels below a hydroelectric dam. J. Fish. Res. Board Can. 29(10):1472-1476.

Fry, F. E. J. 1957. The aquatic respiration of fish, p. 1-64. In M. E. Brown (ed.), The Physiology of Fishes. Vol. 1, Academic Press, Inc., New York.

Gangmark, H. A., and R. G. Bakkala. 1960. A comparative study of stable and unstable spawning areas for incubating king salmon at Mill Creek. Calif. Fish and Game. 46:151-164.

Gangmark, H. A., and R. D. Broad. 1956. Further observations on stream survival of king salmon spawn. Calif. Fish and Game. 42:37-49.

Garside, E. T., and J. S. Tait. 1958. Preferred temperature of rainbow trout (Salmo gairdneri Richardson) and its unusual relationship to acclimation temperature. Can. J. Zool. 36:563-567.

Giger, R. D. 1973. Streamflow requirements for salmonids. Oreg. Wildl. Comm. Job. Final Rep., Proj. AFS 62-1, Portland. 117 p.

Graham, J. M. 1949. Some effects of temperature and oxygen pressure on the metabolism and activity of the speckled trout, Salvelinus fontinalis. Can. J. Res. 27:270-288.

Graham, P. J. 1977. Juvenile steelhead trout densities in the Lochsa and Selway River drainages. M.S. thesis, Univ. Idaho, Moscow. 91 p.

Gray, J. R. A., and J. M. Edington. 1969. Effect of woodland clearance on stream temperature. J. Fish. Res. Board Can. 26(2):399-403.

Greene, G. E. 1950. Land use and trout streams. J. Soil and Water Conserv. 5:125-126.

Hahn, P. J. K. 1977. Effects of fluctuating and constant temperatures on behavior of steelhead trout (Salmo gairdneri). Ph.D. thesis, Univ. Idaho, Moscow. 129 p.

Hall, J. D., and R. L. Lantz. 1969. Effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. p. 355-375. In T. G. Northcote (ed), Symposium on Salmon and Trout in Streams. H. R. MacMillan Lectures in Fisheries. Univ. B.C., Vancouver.

Hamilton, J. A. R., and J. D. Remington. 1962. Salmon and trout of the South Fork Coquille River in relation to the Eden Ridge hydroelectric project. Pac. Power and Light Co., Portland, Oreg. 83 p.

Hanson, D. L. 1977. Habitat selection and spatial interaction in allopatric and sympatric populations of cutthroat and steelhead trout. Ph.D. thesis, Univ. Idaho, Moscow. 66 p.

Hartman, G. F. 1963. Observations on behavior of juvenile brown trout in a stream aquarium during winter and spring. J. Fish. Res. Board Can. 20(3):769-787.

Hartman, G. F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). J. Fish. Res. Board Can. 22(4):1035-1081.

Hartman, G. F. 1969. Reproductive biology of the Gerrard stock of rainbow trout. p. 53-67. In T. G. Northcote (ed.), Symposium on Salmon and Trout in Streams. H. R. MacMillan Lectures in Fisheries. Univ. B.C., Vancouver.

Hausle, D. A., and D. W. Coble. 1976. Influence of sand in redds on survival and emergence of brook trout. Trans. Am. Fish. Soc. 105(1):57-63.

Hayes, F. R., I. R. Wilmot, and D. A. Livingstone. 1951. The oxygen consumption of the salmon egg in relation to development and activity. J. Exp. Zool. 116:377-395.

Hazzard, A. S. 1932. Some phases of the life history of the eastern brook trout, (Salvelinus fontinalis). Trans. Am. Fish. Soc. 62:344-350.

Herrmann, R. B. 1958. Growth of juvenile coho salmon at various concentrations of dissolved oxygen. M.S. thesis, Oreg. State Univ., Corvallis.

Herrmann, R. B., C. E. Warren, and P. Doudoroff. 1962. Influence of oxygen concentrations on the growth of juvenile coho salmon. Trans. Am. Fish. Soc. 91(2):153-167.

Hicks, D. B., and J. W. DeWitt. 1971. Effects of dissolved oxygen on kraft pulp mill effluent toxicity. Water Resour. Res. 5:693-701.

Hoar, W. S., H. A. Keenleyside, and R. G. Goodall. 1957. Reaction of juvenile Pacific salmon to light. J. Fish. Res. Board Can. 14:815-830.

Hobbs, D. F. 1937. Natural reproduction of Quinnat salmon, brown and rainbow trout in certain New Zealand waters. N.Z. Mar. Dep. Fish. Bull. No. 6.

Hoffman, T. C. 1965. Southeastern Alaska pink salmon forecast studies. Preemergent fry program. Alaska Fish and Game Inf. Leafl. 47, Juneau. 29 p.

Holeton, G. F. 1973. Respiration of Arctic char (Salvelinus alpinus) from a high Arctic lake. J. Fish. Res. Board Can. 30(6):717-723.

Hooper, D. R. 1973. Evaluation of the effects of flows on trout stream ecology. Dep. Eng. Res., Pac. Gas and Elec. Co., Emeryville, Calif. 97 p.

Horton, P. A. 1961. The bionomics of brown trout in a Dartmoor stream. J. Anim. Ecol. 30:311-338.

Hourston, W. R., and D. MacKinnon. 1957. Use of an artificial spawning channel by salmon. Trans. Am. Fish Soc. 86:220-230.

Hughes, G. M., and R. L. Saunders 1970. Responses of the respiratory pump to hypoxia in the rainbow trout (Salmo gairdneri). J. Exp. Biol. 53:529-545.

Hunt, R. L. 1969. Effects of habitat alteration on production, standing crops and yield of brook trout in Lawrence Creek, Wis., p. 281-312. In T. G. Northcote (ed.), Symposium on Salmon and Trout in Streams. H. R. MacMillan Lectures in Fisheries. Univ. B.C., Vancouver.

Hunt, R. L. 1976. A long-term evaluation of trout habitat development and its relation to improving management-related research. Trans. Am. Fish. Soc. 105(3): 361-365.

Hunter, J. G. 1959. Survival and production of pink and chum salmon in a coastal stream. J. Fish. Res. Board Can. 16(6):835-886.

Hunter, J. W. 1973. A discussion of game fish in the State of Washington as related to water requirements. Rep. by Fish Manage. Div. Wash. State Dep. Game to Wash. State Dep. Ecol., Olympia. 66 pp.

Hynes, H. B. N. 1970. The ecology of running water. Univ. Toronto Press. 555 p.

Irving, L., E. C. Black, and V. Stafford. 1941. The influence of temperature upon the combination of oxygen with the blood of trout. Biol. Bull. 80: 1-17.

Itazawa, Y. 1970. Characteristics of respiration of fish considered from the arterio-venous difference of oxygen content. Bull. Jap. Soc. Sci. Fish. 36:571-577.

Johnson, R. L., P. E. Giguere, and E. P. Pister. 1966. A progress report on the Pleasant Valley spawning channel. Admin. Rep. No. 66-4. Resour. Agency Calif., Calif. Dep. Fish and Game, Sacramento.

Jones, D. R. 1971. The effect of hypoxia and anemia on the swimming performance of rainbow trout (Salmo gairdneri). J. Exp. Biol. 55:541-551.

Jones, J. W. 1959. The salmon. Collins, London. 192 p.

Kalleberg, H. 1958. Observations in a stream tank of territoriality and competition in juvenile salmon and trout (Salmo salar L. and S. trutta L.). Inst. Freshwater Res. Drottningholm 39:55-98.

Kemp, H. A. 1949. Soil pollution in the Potomac River Basin. Am. Water Works Assoc. J. 41(9):792-796.

Kennedy, H. D. 1967. Seasonal abundance of aquatic invertebrates and their utilization by hatchery reared rainbow trout. U.S. Bur. Sport Fish. and Wildl. Tech. Pap. 12, 41 p.

Kier, W. M. 1964. The stream flow requirements of salmon in the lower Feather River, Butte County, California. Calif. Dep. Fish and Game, Water Proj. Branch, Sacramento. 17 p.

Kimble, L. A., and T. A. Wesche. 1975. Relationship between selected physical parameters and benthic community structure in a small mountain stream. Univ. Wyo., Laramie. Water Resour. Res. Inst. Series 55. 64 p.

Klamt, R. R. 1976. The effects of coarse grantic sediment on the distribution and abundance of salmonids in the central Idaho Batholith. M.S. thesis, Univ. Idaho, Moscow. 85 p.

Koski, K V. 1966. The survival of coho salmon (Oncorhynchus kisutch) from egg deposition to emergence in three Oregon coastal streams. M. S. thesis, Oreg. State Univ., Corvallis. 84 p.

Kraft, M. E. 1968. The effects of controlled dewatering on a trout stream. M.S. thesis, Mont. State Univ., Bozeman. 31 p.

Kraft, M. E. 1972. Effects of controlled flow reduction on a trout stream. J. Fish. Res. Board Can. 29(10):1405-1411.

Kutty, M. N. 1968. Respiratory quotients in goldfish and rainbow trout. J. Fish. Res. Board Can. 25(8):1689-1728.

Kutty, M. N., and R. L. Saunders. 1973. Swimming performance of young Atlantic salmon (Salmo salar) as affected by reduced ambient oxygen concentration. J. Fish. Res. Board Can. 30(2): 223-227.

Larkin, P. A. 1956. Interspecific competition and population control in freshwater fish. J. Fish. Res. Board Can. 13(3): 327-342.

LeCren, E. D. 1965. Some factors regulating the size of populations of freshwater fish. Mitt. Verein. theor. angew. Limnol. 13:88-105.

LeCren, E. D. 1969. Estimates of fish populations and production in small streams in England. p. 269-280. In T. G. Northcote (ed.), Symposium on Salmon and Trout in Streams. H. R. MacMillan Lectures in Fisheries., Univ. B.C., Vancouver.

Lewis, S. L. 1969. Physical factors influencing fish populations in pools of a trout stream. Trans. Am. Fish. Soc. 98(1):14-19.

Lindroth, A. 1942. Sauerstoffverbrauch der Fische. I. Verschiendene Entwicklungs- und Altersstadien vom Lachs und Hecht. Z. vertl. Physiol. 29:583-594.

Linduska, J. P. 1942. Bottom types as a factor influencing the local distribution of mayfly nymphs. Can. Entomol. 74:26-30.

Lister, D. B., and H. S. Genoe. 1970. Stream habitat utilization by cohabiting underyearlings of chinook (Oncorhynchus tshawytscha) and coho (O. kisutch) salmon in the Big Qualicum River, British Columbia. J. Fish. Res. Board Can. 27(7):1215-1224.

Lloyd, R. 1961. Effect of dissolved oxygen concentrations on the toxicity of several poisons to rainbow trout (Salmo gairdneri Richardson). J. Exp. Biol. 38:447-455.

Lucas, K. C. 1959. The Robertson Creek spawning channel. Can. Fish. Cult. 25:4-23.

McAfee, W. R. 1966. Rainbow trout. p. 192-215. In A. Calhoun (ed.), Inland

Fisheries Management. Calif. Dep. Fish and Game, Resour. Agency, Sacramento.

McCuddin, M. E. 1977. Survival of salmon and trout embryos and fry in gravel-sand mixtures. M.S. thesis, Univ. Idaho, Moscow. 30 p.

MacKinnon, D., L. Edgeworth, and R. E. McLaren. 1961. An assessment of Jones Creek spawning channel 1954-1961. Can. Fish. Cult. 3:3-14.

McNeil, W. J. 1966. Effect of the spawning bed environment on reproduction of pink and chum salmon. U.S. Fish and Wildl. Serv. Fish. Bull. 65:495-523.

McNeil, W., J. and W. H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish and Wildl. Serv. Spec. Sci. Rep. Fish. No. 469. 15 p.

Mason, J. C., and D. W. Chapman. 1965. Significance of early emergence, environmental rearing capacity and behaviorial ecology of juvenile coho salmon in stream channels. J. Fish. Res. Board Can. 22(1): 173-190.

Meehan, W. R. 1970. Some effects of shade cover on stream temperatures in southeast Alaska. USDA For. Serv. Res. Note PNW-113, 4 p., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Merrell, T. R., Jr. 1962. Freshwater survival of pink salmon at Sashin Creek, Alaska. p. 59-72. In N. J. Wilimovsky (ed.), Symposium on Pink Salmon. Inst. Fish., Univ. B.C., Vancouver.

Mills, D. H. 1969. Survival of juvenile Atlantic salmon and brown trout in some Scottish streams. p. 217-228. In T. G. Northcote (ed.), Symposium on Salmon and Trout in Streams. H. R. MacMillan Lectures in Fisheries. Univ. B.C., Vancouver.

Moring, J. R. 1975. The Alsea watershed study: effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part III - Discussion and recommendations. Oreg. Dep. Fish and Wildl. Fish. Res. Rep. No. 9, Portland. 24 p.

Moring, J. R., and R. L. Lantz. 1974. Immediate effects of logging on the freshwater environment of salmonids. Oreg. Wildl. Comm., Res. Div., Proj. AFS-58, Final Rep., Portland. 101 p.

Morrill, C. F. and T. C. Bjornn. 1972. Migration response of juvenile chinook salmon to substrates and temperatures. Idaho Water Resour. Res. Inst. Tech. Completion Rep. Proj. A-038-IDA, Moscow. 27 p.

Mundie, J. H. 1969. Ecological implications of the diet of juvenile coho in streams. p. 135-152. In T. G. Northcote (ed.), Symposium on Salmon and Trout in Streams. H. R. MacMillan Lectures in Fisheries, Univ. B.C., Vancouver.

Narver, D. W. 1972. A survey of some possible effects of logging on two eastern Vancouver Island streams. Fish. Res. Board Can. Tech. Rep. 323, 55 p.

Neave, F. 1953. Principles affecting the size of pink and chum salmon populations in British Columbia. J. Fish. Res. Board Can. 9(9):450-490.

Needham, P. R. 1934. Quantitative studies of stream bottom foods. Trans. Am. Fish. Soc. 64:238-247.

Needham, P. R., J. W. Moffett, and D. W. Slater. 1945. Fluctuations in wild brown trout populations in Convict Creek, California. J. Wildl. Manage. 9:9-25.

Needham, P. R., and R. Usinger. 1956. Variability in the macrofauna of a single riffle in Prosser Creek, Calif., as indicated by a Surber sampler. Hilgardia 24:383-409.

Newman, M. A. 1956. Social behavior and interspecific competition in two trout species. Physiol. Zool. 29:64-81.

Nickelson, T. 1976. Development of methodologies for evaluating instream flow needs for salmonid rearing. p. 588-596. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs. Vol. II. Am. Fish. Soc. Spec. Publ.

Nickelson, T. E., and R. E. Hafele. 1978. Streamflow requirements of salmonids. Prog. Rep. Oreg. Dep. Fish and Wildl. AFS-62. Contract 14-16-0001-77-538, Portland. 25 p.

Nickelson, T. E., and R. R. Reisenbichler. 1977. Streamflow requirements of salmonids. Prog. Rep. Oreg. Dep. Fish and Wildl. AFS-62. Contract 14-16-0001-4247, Portland. 24 p.

Orcutt, D. R., B. R. Pulliam, and A. Arp. 1968. Characteristics of steelhead trout redds in Idaho streams. Trans. Am. Fish Soc. 97(1):42-45.

Pautzke, C. F. 1938. Studies on the effect of coal washings on steelhead and cutthroat. Trans. Am. Fish. Soc. 67(1937):232-233.

Pennak, R. W., and E. D. VanGerpen. 1947. Bottom fauna production and physical nature of the substrate in a northern Colorado trout stream. Ecology 28:42-48.

Peters, J. C., and W. Alvord. 1964. Man-made channel alterations in thirteen Montana streams and rivers. Trans. North Am. Wildl. Conf. 29:93-102.

Phillips, R. W., and H. J. Campbell. 1961. The embryonic survival of coho salmon and steelhead trout as influenced by some environmental conditions in gravel beds. 14th Ann. Rep. Pac. Mar. Fish. Comm., Portland, Oreg. p. 60-73.

Phillips, R. W., R. L. Lantz, E. W. Claire, and J. R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Trans. Am. Fish. Soc. 104(3):461-466.

Pollock, R. D. 1969. Tehama-Colusa canal to serve as spawning channel. Prog. Fish-Cult. 31(3):123-130.

Randall, D. J., and J. C. Smith. 1967. The regulations of cardiac activity in fish in a hypoxic environment. Physiol. Zool. 40(2): 104-113.

Rantz, S. E. 1964. Stream hydrology related to the optimum discharge for king salmon spawning in the Northern California Coast Ranges. U.S. Geol. Surv. Water-Supply Pap. 1779-AA. 16 p.

Reiser, D. W., and T. A. Wesche. 1977. Determination of physical and hydraulic preferences of brown and brook trout in the selection of spawning locations. Wyo. Water Res. Inst., Laramie. Ser. No. 64. 100 p.

Ringler, N. H. 1970. Effects of logging on the spawning bed environment in two Oregon coastal streams. M.S. thesis, Oreg. State Univ., Corvallis. 89 p.

Ringler, N. H., and J. D. Hall. 1975. Effects of logging on water temperature and dissolved oxygen in spawning beds. Trans. Am. Fish. Soc. 104(1):111-121.

Rothacher, J. 1971. Regimes of streamflow and their modification by logging. p. 40-54. In Forest Land Uses and Stream Environment, Oreg. State Univ., Corvallis.

Ruggles, C. P. 1966. Depth and velocity as a factor in stream rearing and production of juvenile coho salmon. Can. Fish Cult. 38:37-53.

Ruttner, F. 1953. Fundaments of limnology (Transl. by D. G. Frey and F. E. J. Fry). Univ. Toronto Press. 295 p.

Saunders, J. W., and M. W. Smith. 1962. Physical alteration of stream habitat to improve brook trout production. Trans. Am. Fish. Soc. 91(2):185-188.

Scott, D. 1958. Ecological studies on the Trichoptera of the River Dean, Cheshire Arch. Hydrobiol. 54:340-392.

Sekulich, P. T., and T. C. Bjornn. 1977. The carrying capacity of streams for rearing salmonids as affected by components of the habitat. Completion Rep. for Suppl. 99, USDA For. Serv. 79 p.

Sheridan, W. L. 1962. Waterflow through a salmon spawning riffle in southeastern Alaska. U.S. Fish and Wildl. Serv. Spec. Sci. Rep. - Fish No. 407. 22 p.

Sheridan, W. L. and W. J. McNeil. 1968. Some effects of logging on two streams in Alaska. J. For. 66(2): 128-133.

Shetter, D. S., O. H. Clark, and A. S. Hazzard. 1946. The effects of deflectors in a section of a Michigan trout stream. Trans. Am. Fish. Soc. 76:248-278.

Shumway, D. L., C. E. Warren, and P. Duodoroff. 1964. Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. Trans. Am. Fish. Soc. 93(4):342-356.

Silver, S. T., C. E. Warren, and P. Doudoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and chinook salmon embryos at different water velocities. Trans. Am. Fish. Soc. 92(4): 327-343.

Smith, A. K. 1973. Development and application of spawning velocity and depth criteria for Oregon salmonids. Trans. Am. Fish. Soc. 10(2):312-316.

Smith, L. L., Jr., and J. B. Moyle. 1944. A biological survey and fishery management plan for the streams of the Lake Superior north shore watershed. Minn. Dep. Cons. Div. Game and Fish, Tech. Bull. 1, 228 p.

Smith, O. R. 1939. Placer mining silt and its relation to salmon and trout on the Pacific coast. Trans. Am. Fish. Soc. 69:135-139.

Smith, O. R. 1941. Spawning habits of cutthroat and eastern brook trout. J. Wildl. Manage. 5(4):461-471.

Sprules, W. M. 1947. An ecological investigation of stream insects in Algonquin Park, Ontario. Univ. Toronto Studies, Biol. 56. Publ. Ont. Fish. Res. Lab. 69:1-81.

Stalnaker, C. B., and J. L. Arnette. 1976. Methodologies for determining instream flows for fish and other aquatic life, p. 89-138. In C. B. Stalnaker, and J. L. Arnette (eds.), Methodologies for the Determination of Stream Resource Flow Requirements: An Assessment. U.S. Fish and Wildl. Serv., Office of Biol. Serv., Washington, D.C

Stuart, T. A. 1953. Spawning migration, reproduction and young stages of the Loch trout (S. trutta). Freshwater Salmon. Fish Res. Home Dep., Scotland. Rep. No. 5. 39 p.

Stuart, T. A. 1962. The leaping behavior of salmon and trout at falls and obstructions. Freshwater Salmon. Fish. Res. Rep. No. 28, 46 p.

Stuehrenberg, L. C. 1975. The effects of granitic sand on the distribution and abundance of salmonids in Idaho streams. M. S. thesis, Univ. Idaho, Moscow. 49 p.

Surber, E. W. 1936. Rainbow trout and bottom fauna production in one mile of stream. Trans. Am. Fish. Soc. 66:193-302.

Surber, E. W. 1951. Bottom fauna and temperature conditions in relation to trout management in St. Mary's River, Augusta County, Virginia. Va. J. Sci. 2:190-202.

Tarzwell, C. M. 1937. Experimental evidence on the value of trout stream improvement in Michigan. Trans. Am. Fish. Soc. 66:177-187.

Tarzwell, C. M. 1938. An evaluation of the methods and results of stream improvement in the Southwest. Trans. North Am. Wildl. Conf. 3:339-364.

Tarzwell, C. M. 1957. Water quality criteria for aquatic life. In Biological Problems in Water Pollution. U.S. Dep. Health, Educ. and Welfare, R. A. Taft San. Eng. Cent., Cincinnati, Ohio. p. 246-272.

Tautz, A. F., and C. Groot. 1975. Spawning behavior of chum salmon (O. keta) and rainbow trout (S. gairdneri). J. Fish. Res. Board Can. 32(5):633-642.

Tebo, L. B., Jr. 1955. Effects of siltation resulting from improper logging on the bottom fauna on a small trout stream in the southern Appalachians. Prog. Fish-Cult. 17(2):64-70.

Tebo, L. B., Jr. 1957. Effects of siltation on trout streams. Soc. Am. For. Proc. 1956 Meeting, p. 198-202.

Tebo, L. B., Jr. 1974. Review of selected parameters of trout stream quality. In Symposium on Trout Habitat Research and Management. Appalachian Consortium Press. Boone, N.C. p. 20-32.

Terhune, L. D. B. 1958. The Mark VI groundwater standpipe for measuring seepage through salmon spawning gravel. J. Fish. Res. Board Can. 15(5):1027-1063.

Thompson, K. 1972. Determining stream flows for fish life. In Proceedings, Instream Flow Requirement Workshop, Pac. Northwest River Basin Comm., Vancouver, Wash. p. 31-50.

Thorup, J. 1966. Substrate type and its value as a basis for the delimitation of bottom fauna communities in running waters. p. 59-74. In K. W. Cummings, C. A. Tryon, Jr., and R. T. Hartman (eds.), Organism-Substrate Relationships in Streams. Spec. Publ. No. 4., Pymatuning Lab. of Ecology, Univ. Pittsburg, Pa.

Trautman, M. B. 1933. The general effects of pollution on Ohio fish life. Trans. Am. Fish Soc. 63:69-72.

Vaux, W. A. 1962. Interchange of stream and intragravel water in a salmon spawning riffle. U.S. Fish and Wildl. Serv. Spec. Sci. Rep. Fish. 405. 11 p.

Vaux, W. A. 1968. Intragravel flow and interchange of water in a streambed. U.S. Fish and Wildl. Serv. Fish Bull. 66:479-489.

Wallen, E. I. 1951. The direct effect of turbidity on fishes. Okla. Agric. and Mech. Col., Arts and Sci. Studies, Biol. Ser. No. 2, 48(2):27.

Warner, K. 1963. Natural spawning success of landlocked salmon (Salmo salar). Trans. Am. Fish. Soc. 92(2):161-164.

Warner, K., and I. Porter. 1960. Experimental improvement of a bulldozed trout stream in Northern Maine. Trans. Am. Fish. Soc. 89(1):59-63.

Waters, B. F. 1976. A methodology for evaluating the effects of different streamflows on salmonid habitat. p. 254-266. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs. Vol. II. Am. Fish. Soc. Spec. Publ.

Waters, T. F. 1969. Invertebrate drift--ecology and significance to stream fishes. p. 121-134. In T. G. Northcote (ed.), Symposium on Salmon and Trout in Streams. H. R. MacMillan Lectures in Fisheries. Univ. B.C., Vancouver.

Watts, F. J. 1974. Design of culvert fishways. Idaho Water Resour. Res. Inst. Rep. Proj. A-027-IDA, Moscow. p. 62.

Wells, R. A., and W. J. McNeil. 1970. Effect of quality of spawning bed on growth and development of pink salmon embryos and alevins. U.S. Fish and Wildl. Serv. Spec. Sci. Rep. Fish. No. 616. 6 p.

Wesche, T. A. 1973. Parametric determination of minimum stream flow for trout. Wyo. Water Resour. Ser. No. 37. Water Resour. Res. Inst. Univ. Wyo., Laramie. 102 p.

Wesche, T. A. 1974. Relationship of discharge reductions to available trout habitat for recommending suitable streamflows. Wyo. Water Resour. Res. Inst., Laramie. Ser. No. 53. 71 p.

White, R. G. 1976. Predicted effects of water withdrawal on the fish populations of the Teton River, Idaho. Completion Rep. to U.S. Bur. Reclam., For. Wildl. and Range Exp. Stn. Contrib. No. 63, Univ. Idaho, Moscow. 47 p.

Whitmore, C. M., C. E. Warren, and P. Doudoroff. 1960. Avoidance reactions of salmonids and centrachid fishes to low oxygen concentrations. Trans. Am. Fish. Soc. 89(1):17-26.

Wickett, W. P. 1951. The coho salmon populations of Nile Creek. Fish. Res. Board Can., Prog. Rep. (Pac.) No. 89:88-89.

Wickett, W. P. 1954. The oxygen supply to salmon eggs in spawning beds. J. Fish. Res. Board Can. 11(6):933-953.

Wickett, W. P. 1958. Review of certain environmental factors affecting the production of pink and chum salmon. J. Fish. Res. Board Can. 15(5):1103-1126.

Wickett, W. P. 1962. Environmental variability and reproduction potentials of pink salmon in British Columbia, p. 73-86. In N. J. Wilimovsky (ed.), Symposium on Pink Salmon 1960. H. R. MacMillan Lectures in Fisheries. Univ. B.C., Vancouver.

Wickham, G. M. 1967. Physical microhabitat of trout. M.S. thesis, Colo. State Univ., Fort Collins. 42 p.

Ziebell, C. D. 1957. Silt and pollution. Wash. Pollut. Control Comm. Info. Ser. 57-1. 4 p.

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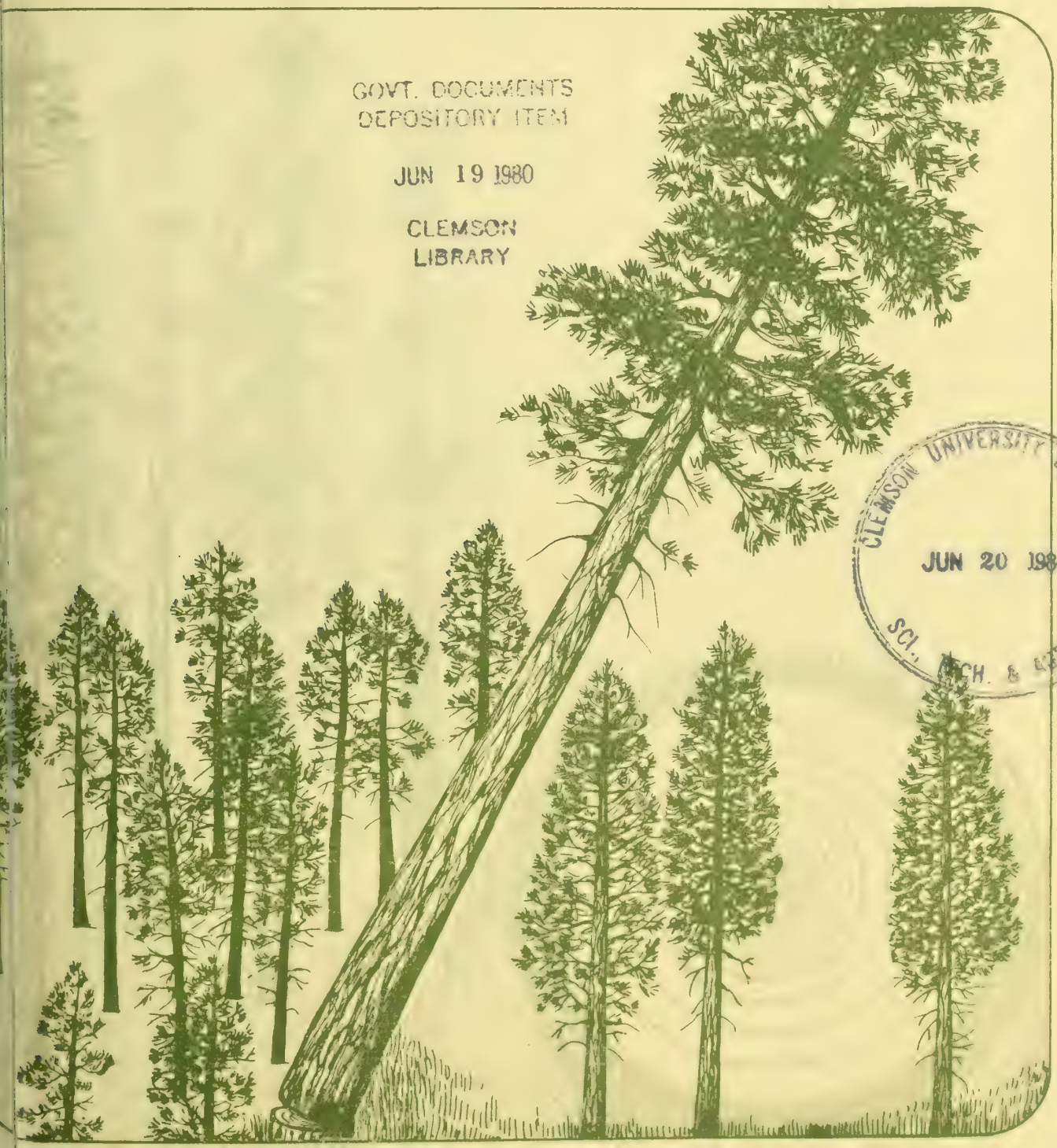
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Silviculture of Ponderosa Pine in the Pacific Northwest: The State of Our Knowledge

James W. Barrett



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Abstract

The silviculture of ponderosa pine in the Pacific Northwest States of Washington and Oregon is described. The timber resource, growth, and value are discussed first, followed by damaging agents, management, and silviculture. Relevant literature is presented along with observations, experience, and results of unpublished work. Research needs for the future are also proposed.

KEYWORDS: Silviculture, ponderosa pine, Pinus ponderosa, Pacific Northwest.

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INTRODUCTION

The ponderosa pine[1/] forests of the Pacific Northwest have furnished the most accessible timber to farms, mines, and settlements in the central and eastern parts of the Pacific Northwest States since 1860. In addition to a wide variety of wood products, these lands provided abundant grazing for livestock and cover for big game and other wildlife. Recognized as a truly great asset of eastern and southwestern Oregon and eastern Washington, these forests also afford hunting, fishing, camping, and cross-country skiing.

These pine forests are prime examples of how multiple-use management can work; their varied use provides silviculturists with the ultimate challenge. Forest managers are progressing rapidly into intensive management, particularly on the more productive sites. At the same time, managers are being asked to improve forestry practices to protect or improve the forest environment. To meet this challenge, the forester needs a readily available pool of knowledge to make sound management decisions. Fortunately, information about ponderosa pine and its environment has been accumulating for almost 60 years throughout the entire West and for at least 40 years in the Pacific Northwest.

The purpose of this report is to bring together most of what is known about the silviculture of ponderosa pine in the Pacific Northwest. It is intended as a reference for the forest manager and contains the more important facts published about the species in this region plus some previously unpublished data. The silviculture of ponderosa pine for timber production has been emphasized, although other aspects such as grazing, forage for wildlife, and succession have also been touched upon.

I encourage the reader to make use of the literature citations, where more complete coverage will be found. Documented ponderosa pine research cited here comes from throughout the Pacific Northwest, but a notable portion comes from experiments and observations in central Oregon from the USDA Forest Service research facility at Bend, Oregon, and the nearby Experimental Forest, which has a large component of pine. Note that a bibliography on ponderosa pine in the Western United States has been compiled by Axelton (1967, 1974) through 1965 and from 1966 to 1970. With today's computerized library retrieval systems, you need only minutes and a phone call to a major college or university library to be in touch with the latest written information on silvicultural practice. In addition, State and national extension services are available to everyone. Much knowledge and expertise is at hand for solving difficult problems.

Past performance on both public and private land has clearly demonstrated that silvicultural practice is much better based on available knowledge rather than on some personal philosophy founded on suspected influences. When information really is lacking, then keen observation, analysis, and

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[1/] Scientific names of plants and animals mentioned in this paper are given in appendix table 11.

rational decisionmaking are even more necessary. Acquiring knowledge is cheap compared to the resources wasted when operations are conducted in ignorance (Smith 1962).

PAST AND PRESENT

Ponderosa pine forests in the Northwest have been providing useful wood products for over a century. Some cutting for farms, mines, and towns began about 1860, but commercial timber harvesting--mostly on private lands--began late in the 1800's and increased gradually over the next 25 years. Extensive cutting on National Forest land did not begin until about 1910 when railroads were widely available.

On private lands, the first entry was usually an economic clearcutting, dictated by the high fixed cost of railroad logging. Most cutting on Federal lands was by partial cutting, which left some reserve trees for later cuts and as a source of seed. The McGifford and Ledgerwood steam skidders yarded logs into a loading point on the railroad. The old skid trails from these operations are still visible from the air, looking like the spokes of a wheel. Some of the reproduction was apparently already established when the logs were skidded. Fortunately, this has provided some well-spaced stands that grew at acceptable rates for many years after logging.

Logging slash was treated in various ways and frequently without regard to regeneration. Often nothing was done and slash was left to decompose slowly or was broadcast burned as prescribed by State law. If the burning conditions were right, a good seedbed was prepared for the next crop of trees. The only seed trees available after cutting, however, were those unsuitable for milling, never the best trees from the original stand. Occasionally, fires started in the slash from lightning or by human activity and raged out of control over vast acreages. Some of these burned areas developed into brush and remained difficult to regenerate.

After World War II, railroad logging gave way to a new technology based on logging trucks and skidding by caterpillar tractor. The new technology changed the cost basis of the industry and opened the way for management practices that called for lighter cutting on public and some private lands.

Lighter cutting provided an opportunity to reach the vast uncut areas of public land in a short time and to establish a road system badly needed for the suppression of wildfires in the virgin forests. Losses caused by bark beetles during the drought years of the 1930's were so heavy that some foresters thought pine forests would be totally destroyed. Entomologists discovered that they could identify high-risk trees. Not only were these the trees that were the most likely to be killed, but they were also the ones that "produced" more beetles. Consequently, removal of high-risk trees tended to "bug proof" the remaining stand. Light, sanitation-salvage cutting fit in nicely with cutting to "road" the forest for protection.

This type of cutting continued until the early 1960's. Foresters then began to look with admiration at some of the even-aged stands that developed, by good fortune, after the early clearcutting. The trend toward even-aged managing of some stands continues to gain favor among present-day managers.

THE TIMBER RESOURCE

Value

Ponderosa pine dominates about 36 percent of the commercial forest land in eastern Oregon and Washington. The species also occurs as an important component in the mixed conifer stands throughout the pine region. The combined value of products produced from the type in the two States during 1976 was 569 million dollars, indicating that the species is a resource worthy of the most prudent management.

Recent inventories have shown a marked drop in acres of commercial forest land dominated by ponderosa pine. Cutting practice and fire control appear to be the main reasons for this conversion. Periodic ground fires before fire control kept species such as the true firs and Douglas-fir from becoming established in the understories of pure pine stands. With the exclusion of fire has come a massive intrusion of reproduction of other species on the better sites. Thus, when the mature pine is harvested, the land is typed as either mixed conifer or a single species other than ponderosa pine. About 5 million acres are believed to have changed type classification in the last 25 years.

Commercial Areas and Volumes

Stands dominated by ponderosa pine occupy about 6.7 million of the 19.5 million acres (2.71 to 7.89 million ha) of commercial forest land east of the Cascade Range. Only about 4 percent of this total land area in forest is nonstocked. Oregon contains over twice as much land in the ponderosa pine type as Washington.

Oregon has 69 percent of the ponderosa pine growing stock and 71 percent of the sawtimber (table 1). The National Forest System administers about 64 percent of the sawtimber volume east of the Cascade Range in both States; average volume per acre in Oregon is about 13,300 fbm and 12,500 in Washington.

A marked imbalance is now apparent in the size-class distribution. About 73.5 percent of the land is sawtimber, with only 16.5 percent in poles and 10 percent in seedlings and saplings (table 2). This poses a challenge for pine managers over the next several decades. On the encouraging side, much of the land in sawtimber has an understory of seedlings, saplings, and poles in various degrees of suppression.

Table 1--Volume of ponderosa pine growing stock and sawtimber on commercial forest land in eastern Oregon and eastern Washington (1977)[1/]

Area	Total growing stock			Sawtimber only		
	Total all owners	ONF[2/]	NFA[3/]	Total all owners	ONF[2/]	NFA[3/]
	Million cubic feet (Cubic meters)			Million board feet[4/]		
Eastern Oregon	8,257 (234)	2,260 (64)	5,997 (170)	45,672	10,067	35,605
Eastern Washington	3,704 (105)	2,820 (80)	884 (25)	19,095	13,549	5,546
Total	11,961 (339)	5,080 (144)	6,881 (195)	64,767	23,616	41,151

[1/]Source: Forest Research Evaluation Work Unit, Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. Prepared for 1980 Resources Planning Act assessment.

[2/]Other than National Forest.

[3/]National Forests.

[4/]International 1/4-inch rule.

Over 50 percent of the land can produce 50 to 80 ft^3 (3.5 to 5.6 m^3/ha) of wood per acre per year (table 3) or roughly 300-500 fbm. Also, encouraging is the estimate that 25 percent of the land area can produce more than 85 ft^3 per acre (5.9m^3/ha) per year.

About 90,000 acres (36 422 ha) (Bassett 1977) or a little over 1 percent of the total land area dominated by ponderosa pine in the region occurs in southwestern Oregon. Ponderosa pine does, however, occur interspersed with Jeffrey pine, true fir, and Douglas-fir types in this area.

Table 2--Area of forest land in the ponderosa pine type by ownership and stand size classes compared with total commercial forest land in 1977 for eastern Oregon and Washington[1/]

Ownership	Stand size class						All stands		Total commercial forest land		Total in ponderosa pine
	Sawtimber		Poletimber		Seedlings						
	Thousand acres (hectares)										Percent
OREGON											
National Forest	2,390	(967)	440	(178)	297	(120)	3,127	(1 266)	7,046	(2 851)	44
Other public	147	(60)	41	(17)	28	(11)	216	(87)	584	(236)	37
Forest industry	549	(222)	130	(53)	59	(24)	738	(299)	1,627	(658)	45
Private	346	(140)	152	(62)	58	(24)	556	(225)	1,251	(506)	44
All ownership	3,432	(1 389)	763	(309)	442	(179)	4,637	(1 877)	10,508	(4 252)	44
WASHINGTON											
National Forest	337	(136)	48	(19)	28	(11)	413	(167)	2,967	(1 201)	14
Other public	639	(259)	103	(42)	78	(32)	820	(332)	2,268	(918)	36
Forest industry	201	(81)	37	(15)	38	(15)	276	(112)	738	(299)	37
Private	328	(133)	157	(64)	87	(35)	572	(232)	2,193	(888)	26
All ownership	1,505	(609)	345	(140)	231	(94)	2,081	(842)	8,166	(3 305)	25
Total Oregon and Washington	4,937	(1 998)	1,108	(448)	673	(272)	6,718	(2 719)	[2/]18,674	(7 557)	36

[1/]Source: Forest Research Evaluation Work Unit, Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. Prepared for 1980 Resources Planning Act assessment.

[2/]There are 19,516,000 acres (7 898 000 ha) of commercial forest land in eastern Oregon and Washington, but 842,000 acres (340 759 ha) are not adequately stocked with trees.

Table 3--Percent of ponderosa pine type by productivity classes in eastern Oregon and Washington[1/]

Ownership	Productivity class (annual growth in cubic feet per acre)			
	20-50	50-85	85-120	120+
	Percent of land area in ponderosa pine			
OREGON				
National Forest	22	59	17	2
Other public	27	48	12	13
Forest industry	26	58	15	1
Private	56	32	10	1
WASHINGTON				
National Forest	27	41	23	8
Other public	12	52	30	6
Forest industry	5	44	40	11
Private	13	48	34	5

[1/]Source: Forest Research Evaluation Work Unit, Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. Prepared for 1980 Resources Planning Act assessment.

Harvest and Growth

Annual harvest now exceeds growth in both sawtimber and growing stock volume in ponderosa pine. In cubic-foot growing stock of all ownerships, we are cutting about 50 percent more than growth and in sawtimber, about 80 percent more than growth (tables 4 and 5). On National Forest land, the percentages are even greater. This is not unique to the ponderosa pine type; throughout the entire West, net growth of softwood growing stock in 1970 was about 22 percent less than removals. Net growth of softwood sawtimber was 46 percent less than removals (U.S. Department of Agriculture 1974). These apparent imbalances between cut and growth in the West are not viewed as serious because a large portion of the harvest is from old-growth stands where harvests can exceed growth for some time. In the East, where mature old-growth timber has been gone for many years, net growth (cubic feet) of eastern softwoods in 1970 exceeded removals by 48 percent. As mature ponderosa pine is replaced by vigorously growing young stands, growth will eventually equal and probably exceed cut.

Table 4--Net annual growth of ponderosa pine growing stock and sawtimber in eastern Oregon and eastern Washington (1977)[1/]

Half of State	Growth on growing stock			Growth on sawtimber		
	Total all owners	ONF[2/]	NFA[3/]	Total all owners	ONF[2/]	NFA[3/]
	Thousand cubic feet (Cubic meters)			Thousand board feet[4/]		
Eastern Oregon	119,200 (3 375)	54,000 (1 529)	65,200 (1 846)	518,000	231,800	286,200
Eastern Washington	54,800 (1 552)	48,400 (1 371)	6,400 (181)	310,400	274,500	35,900
Total	174,000 (4 927)	102,400 (2 900)	71,600 (2 028)	828,400	506,300	322,100

[1/]Source: Forest Research Evaluation Work Unit, Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. Prepared for 1980 Resources Planning Act assessment.

[2/]Other than National Forest.

[3/]National Forest.

[4/]International 1/4-in rule.

Table 5--Net annual cut of ponderosa pine growing stock and sawtimber in eastern Oregon and eastern Washington[1/]

Half of State	Growing stock			Sawtimber		
	Total all owners	ONF[2/]	NFA[3/]	Total all owners	ONF[2/]	NFA[3/]
	Thousand cubic feet (Cubic meters)			Thousand board feet[4/]		
Eastern Oregon	201,000 (5 692)	92,600 (2 622)	108,400 (3 070)	1,130,800	558,500	572,300
Eastern Washington	66,600 (1 886)	53,500 (1 515)	13,100 (371)	374,600	309,800	64,800
Total	267,600 (7 578)	146,100 (4 137)	121,500 (3 441)	1,505,400	868,300	637,100

[1/]Source: Forest Research Evaluation Work Unit, Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. Prepared for 1980 Resources Planning Act assessment.

[2/]Other than National Forest.

[3/]National Forest.

[4/]International 1/4-in rule.

REGIONAL PHYSIOGRAPHIC FEATURES

In few other places in the United States can such a variety of landforms be found as in the Pacific Northwest (fig. 1). Elevations range from sea level to over 14,600 ft (4 450 m). Flat river valleys, rolling hills, and precipitous slopes can be found, and frequently these changes in land form occur within just a few miles. As would be expected, a wide variety of soils are found which, in combination with a variable climate, influence the distribution of ponderosa pine and accompanying understory vegetation.

Volcanism in the Cascade Range has greatly influenced soils, although sedimentary and metamorphic rocks abound. Extensive mantles of pumice and ash cover large areas. Because many of these volcanic soils are young and rainfall is limited east of the Cascade Range, little profile development has taken place. Marked changes in the rainfall pattern caused by the Cascade Range rainshadow produce abrupt soil changes.

The highly variable soils and geologic features make silviculture most challenging in this region.

Ponderosa pine occurs as extensive pure stands in 9 of the 15 physiographic and geological provinces (Franklin and Dyrness 1973; Little 1971) of Oregon and Washington (fig. 2): Okanogan Highlands, Northern Cascades, Southern Washington Cascades, Columbia Basin, High Cascades, Blue Mountains, High Lava Plains, Basin and Range, and Klamath Mountains. The species is also found in the Puget Trough, Olympic Peninsula, Willamette Valley, and Western Cascades Provinces. Only those geological provinces where ponderosa pine can occur as the predominant species will be reviewed.

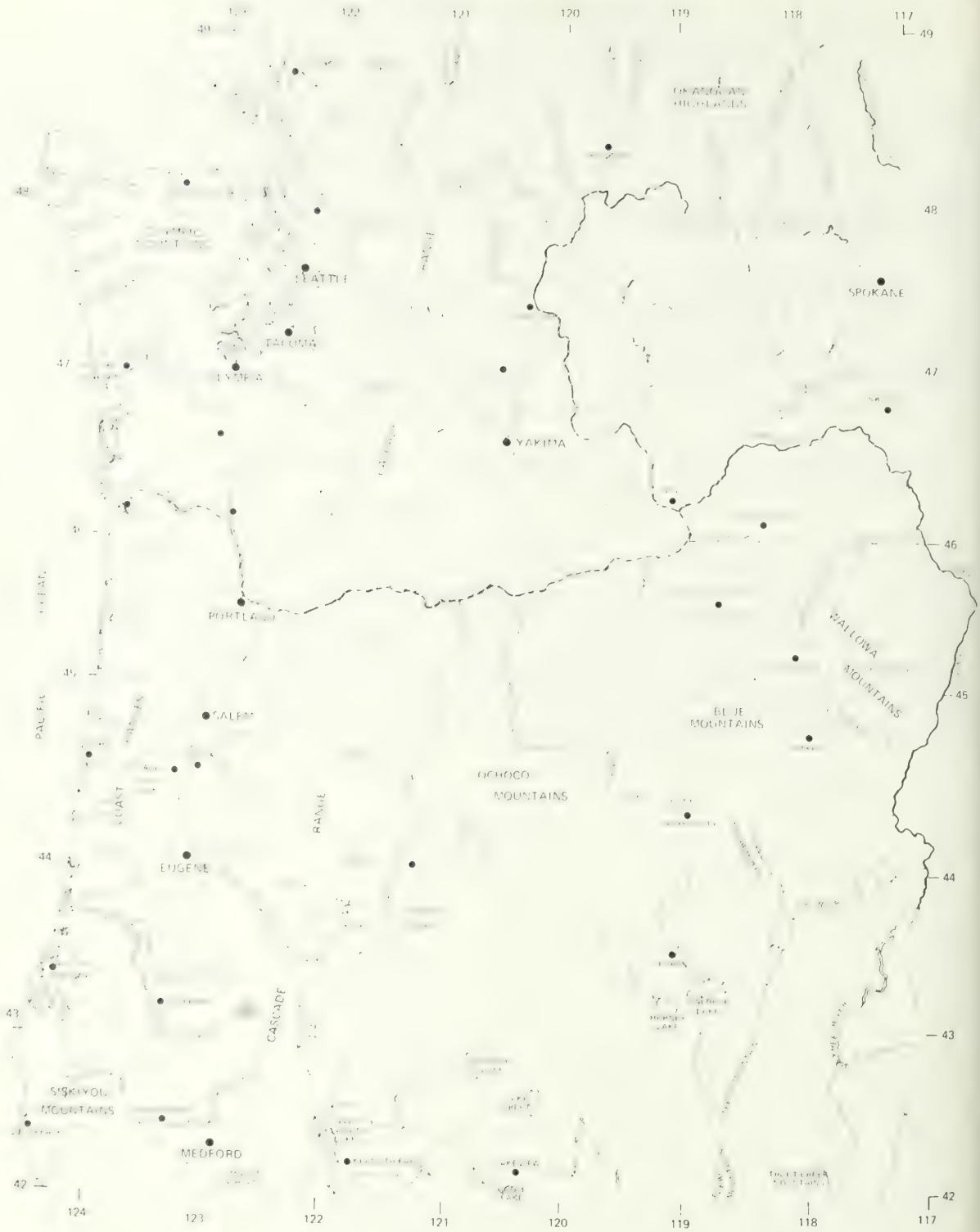


Figure 1.--Major topographic features and some cities and towns in Oregon and Washington.

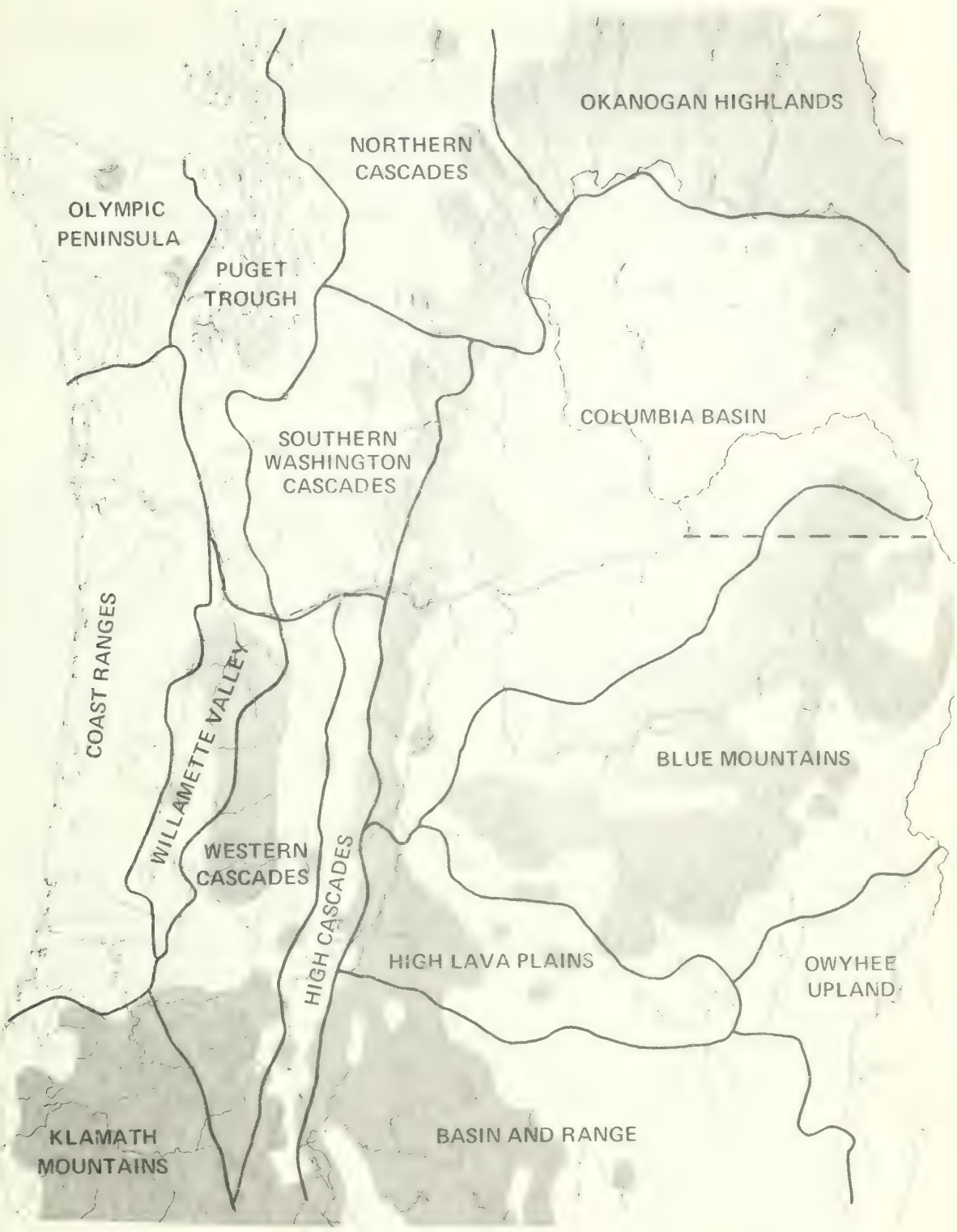


Figure 2.--Physiographic and geological provinces in Oregon and Washington (Franklin and Dyrness 1973) and the distribution of ponderosa pine, shaded area (Little 1971).

GEOLOGICAL PROVINCES, SOILS, AND PONDEROSA PINE DISTRIBUTION

Okanogan Highlands Province

Ponderosa pine is found throughout the province as a principal component of mixed conifer stands and occasionally in pure stands.

The Okanogan Highlands consist of moderate slopes and broad, mounded summits. Much of the province lies above 3,937 ft (1 200 m) except for main river valleys. Six major rivers--the Methow, Okanogan, Sanpoil, Columbia, Colville, and Pend Oreille--divide the province into several upland areas. Deposits of glacial drift are found throughout, because virtually the entire province was repeatedly covered by glacial ice. A great variety of rock types represent Precambrian to late Tertiary. The most abundant of these are granitics, deposited during the Mesozoic.

Soil types are closely tied to elevation. In the mountains at higher elevations, soils derived from granitic parent materials are Xerochrepts (Regosols) and Cryorthods (Podzols). The xerochrepts have weak horizon development, are cold, acid, stony or gravelly sandy loam, with a total depth to bedrock of about 3.3 ft (1 m). The Cryorthods have substantially more profile development, with a light-colored A2 horizon underlain by a B2 horizon of high iron content. Texture tends to be a silt loam.

In the transitional forest grassland areas along rivers, the most abundant parent material is glacial till with a sandy loam texture. These Haploxerolls (Chernozem soils) have a dark, moderately thick A1 horizon underlain by a B horizon with little clay and distinguished by changes in color and structure.

Northern Cascades Province

This province is comprised to a large extent of ancient sedimentary rocks, most of which are folded and at least partially metamorphosed. Intrusions of large granitic batholiths are also common. It is topographically mature with great relief; valleys are very deep and steep sided.

Soils east of the Cascade crest, where ponderosa pine is found, reflect the relatively dry conditions under which they were formed. Most prevalent are Haploxerolls (Chestnut and Brown soils) formed on a variety of parent materials but generally influenced to some extent by volcanic ash and, in some areas, loess. Stone-free silt loams to cobbly loams can be found. Other soils in the eastern portion include Xerochrepts (Regosols) and Haploxeralfs (Noncalcic Brown soils).

Southern Washington Cascades Province

Ponderosa pine is found mostly as a major or minor component of mixed conifer stands in this province. Its distribution is confined mostly to the eastern slopes of the Cascade Range.

The area is made up of generally conforming ridge crests separated by steep, deeply dissected valleys. Andesite and basalt flows dominate, with only minor amounts of igneous intrusive, sedimentary, and metamorphic rocks.

Soils east of the Cascade crest are mostly Haploxeralfs (Noncalcic Brown soils) and Haploxerolls (Chestnut soils). These soils, derived from andesite, sandstone, or glacial till, are also influenced by volcanic ash or loess or both. Soil textures are most often silt loams and loams.

Columbia Basin Province

Ponderosa pine is found on about the entire perimeter of the province and invades the province extensively in south central and northeastern Washington (fig. 2). In general, precipitation is heaviest along the margins of the basin (16 to 24 in (41 to 61 cm) annually) and gradually decreases toward the central portion. In all but the west boundary area, Argixeroll soils predominate (Prairie soils and Chernozems). On the western border, soils have been largely influenced by volcanic activity and have characteristics similar to those found in the Southern Washington Cascades and High Cascades provinces.

High Cascades Province

Ponderosa pine is evident at the lower elevations where it is often an important component of mixed conifer stands. It is found in extensive pure stands in the eastern portion. The area is dominated by a series of prominent mountain peaks. From the northern part of Oregon to the southern border, they are: Mount Hood, 11,235 ft (3 424 m); Mount Jefferson, 10,497 ft (3 199 m); Three Fingered Jack, 7,841 ft (2 390 m); Mount Washington, 7,794 ft (2 376 m); the Three Sisters, 10,094 ft (3 077 m), 10,053 ft (3 064 m), and 10,354 ft (3 156 m); Mount Thielsen, 9,182 ft (2 799 m); Mount Scott, 8,938 ft (2 724 m); and Mount McLaughlin, 9,495 ft (2 894 m).

This province is geologically young, with some lava flows only several hundred years old. The central and southern parts of the province are covered with deposits of volcanic material such as pumice, cinders, and ash. The most extensive deposit of this material resulted from the eruption of Mount Mazama (Crater Lake) about 6,600 years ago. Soils in this volcanic material show little profile development and are classed as Vitrandepts (Regosols). They ususally exhibit a thin, dark A1 horizon of sandy loam or loamy sand underlain by a transitional AC horizon that grades into a course sand or gravelly sand parent material.

Blue Mountains Province

Ponderosa pine grows extensively throughout this province either in pure stands or as a component of mixed conifer forests. Faulted valleys and synclinal basins separate the mountain ranges. These ranges include the Ochoco, Blue, and Wallowa Mountains, as well as the Strawberry, Greenhorn, and Elkhorn Ranges. Slopes in the Blue and Ochoco Mountains are moderate, but the heavily glaciated Wallowa Mountains exhibit great relief. Maximum elevations range from about 6,890 ft (2 100 m) in the Ochoco Mountains to 9,515 ft (2 900 m) at Eagle Cap in the Wallowa Mountains. In the Ochocos, valleys are about 2,500 ft (762 m); and between the Blue and Wallowa Mountains, valleys are 2,950 ft (899 m). Columbia River basalt occupies large areas within the western Blue Mountains.

After the most recent lava flows, much of the area within the central and northern portions of the Blue Mountains was covered by a layer of aerially deposited volcanic ash and fine pumice. Through the centuries, erosion has largely removed the ash from south-facing slopes. Other locations are typically mantled by the material. Many upland areas--especially in the eastern portion of the province--were covered by loess.

High Lava Plains Province

Ponderosa pine is confined mostly to the western portion of this province and also occurs in two isolated areas in the center.

Recent lava flows, cinder cones, and lava buttes characterize this province in central Oregon. Because of low rainfall, many streams flow seasonally and only drain the snowfields high in the Cascade Range.

Extensive volcanic activity took place during the Pleistocene and recent times, especially in the western portion of the province. Paulina Peak, the volcano containing Newberry Crater, erupted about 4,000 years ago, and pumice mantles an extensive area to the north and east of the crater. Mount Mazama pumice is also widespread in the same general area, as well to the south in the Basin and Range province.

On the eastern slopes of the Cascades that support coniferous forests, we find regosolic soils developed on pumice.

Basin and Range Province

Ponderosa pine is found in pure stands over vast areas throughout the western third of the province. At higher elevations, it is an important component of a mixed conifer stand.

This province is characterized by fault-block mountains enclosing basins with internal drainage. Prominent topographic features from west to east are the Klamath Lake Basin, Goose Lake Valley, Winter Rim, Summer Lake, Chewaucan Basin, Abert Lake Basin, Abert Rim, Warner Mountain, Warner Valley, Hart Mountains, Catlow Valley, the Steens and Pueblo Mountains, the Alvord Desert, and the Owyhee Valley.

The province is made up largely of Miocene-to-recent flows of basalt and alluvial sediments. The soils in the western portion developed under forest vegetation. The high plateau area in the northwestern corner is covered with vast deposits of Mazama pumice. Some of the pumice was aerially deposited and some deposited in glowing avalanches that swept down the slopes adjacent to the volcano. Some, but not all, of this material has been reworked by water.

Soils in the area derived from pumice have immature profiles with a moderately thick surface layer with some organic matter accumulation overlying nearly unweathered, yellow and buff pumice gravel and sand. They are slightly acid soils. Because of the high porosity of pumice, this coarse material has water-holding and cation-exchange capacities far greater than would be expected.

Klamath Mountains Province

Ponderosa pine occurs in the eastern three-fourths of the province, sometimes in pure stands, but mostly associated with other species.

The Klamath Mountains are in the southwestern corner of Oregon, south of the Coast Ranges and west of the Cascade Range. The northern portion of these mountains is often called the Siskiyou Mountains. The mountains are rugged with narrow canyons and 2,000 to 5,000 ft (610 to 1 524 m) of relief. They are made up largely of pre-Tertiary strata that have been folded, faulted, and in places intruded by granitoid rocks and serpentinized masses of ultrabasic rocks (Baldwin 1964). Mount Ashland (7,530 ft, 2 295 m) is the highest peak in the Klamath Mountains; to the west, the summits gradually diminish to about 2,500 ft (762 m) before the land breaks off to a narrow coastal plain. The Rogue and Smith Rivers and their tributaries and a few short coastal streams drain the area.

Soils are in two main groupings: in the eastern half, they reflect the effects of drier conditions, especially during the summer; in the western portion, they tend to remain moist considerably longer.

Upland soils in the western half are for the most part Haplohumults (Reddish Brown Lateritic soils). Parent materials for these soils include both sedimentary and basic igneous rocks. The western portion of the province contains a wide variety of valley-bottom soils. The most important, well-drained soils derived from alluvium on terrace landforms are Dystrandepts and Haplumbrepts. In the eastern half of the province, the principal

upland soils are Haploxerults (Reddish Brown Lateritic soils), which are continuously dry for a long period of the year. Generally, these are reddish-brown soils derived from sedimentary parent material with bedrock within 1 m of the surface.

Soils on flood plains and alluvial fans in the eastern section of the Klamath Mountain province are principally well-drained Haploxerolls and Haploxeralfs (Prairie soils). For a more complete description of the vegetation in these provinces, consult Franklin and Dyrness (1973).

CLIMATE

The climate of Oregon and Washington is extremely varied and complex because of the interplay between ocean and continental air masses. Most moisture-laden storms approach Oregon and Washington from the west in cyclonic low-pressure systems. These storms shift to the north in the summer, and high-pressure systems off the coast bring dry weather for long periods.

The Cascade Range, which extends from the Canadian border through Washington and Oregon to northern California, forms a vast barrier for the moist air from the Pacific Ocean. During the winter, moisture-laden air masses of the low-pressure system move inland and are forced upward by the Coast and Cascade Ranges. This air is cooled, condensed, and precipitates mostly on the west-facing, windward slopes. The east-facing lee slopes receive much less rainfall. Thus, eastern Oregon and Washington are in a gigantic rain shadow. Much of this moist air from the Pacific falls west of the Cascade crest, although strong pressure systems occasionally force the moisture-laden air over the crest. Higher elevations then receive notable amounts of precipitation, but the lower valleys are dry and usually nonforested.

Most precipitation falls as snow east of the Cascades. Summers are dry, especially during July, August, and September. Average annual precipitation ranges from about 10 to 21 in (25 to 53 cm), with only 2 to 6 in (5 to 15 cm) falling during the growing season. Elevation can have a profound effect on precipitation. Within the type, an increase of 800 ft (244 m) in elevation is often accompanied by an increase of 8 in (20 cm) in precipitation. Ponderosa pine is found as elevation and precipitation increase above the valley floor and with further increases, other species begin to accompany it. Climate, especially precipitation, is important in the natural distribution of pine and an important consideration in artificial regeneration of the species.

Average annual temperatures in the western ponderosa pine type are between 41.8° and 49.8°F (5.4° and 9.9°C), and average July-August temperatures between 62.0° and 69.6°F (16.7° and 20.9°C). Annual extremes are -40° to 110°F (-40° to 43°C) (Fowells 1965). During the growing season, temperatures fluctuate widely from day to night, with ranges of 54°F (12.2°C) possible. Frost may occur any night of the

year, and cold air drainage pockets are frequent in Oregon. Frost and frost-heaving also influence the distribution of ponderosa pine; lodgepole pine, for example, is more tolerant of frost than ponderosa pine (Cochran and Berntsen 1973).

DAMAGING AGENTS

Various diseases, insects, mammals, and birds affect ponderosa pine from seedling stage to maturity. Although relations of damaging agents are frequently complex, the literature abounds with research that explains symptoms, life cycles, and control measures. As environmental constraints become more stringent and management intensity increases, the silviculturist will be challenged to manipulate trees and vegetation so that destructive pests are subdued to tolerable levels. Knowledge about life cycles or contagion will aid the silviculturist in prescribing control for these pests.

Diseases

DWARF MISTLETOE

Western dwarf mistletoe, a dioecious flowering plant, parasitizes ponderosa pine and can reduce tree growth. Seed-bearing plants and staminate flowers appear on the host in roughly equal numbers or--under conditions for poor growth--are absent. The forcefully disseminated, adhesive seeds are intercepted by the needles, wash to the stems, germinate, and send sinkers into the current year's tissue. Growth of the mistletoe in the cambium area disrupts the normal flow of photosynthates and water in and around the infected area.

Although the disease is a serious consideration in the management of ponderosa pine in this area, it appears less devastating than the southwestern dwarf mistletoe found in southwestern United States (Lightle and Weiss, 1974). In the Northwest, we probably have a distinctly better chance for cultural manipulation of infected stands than in the Southwest (Strand and Roth 1976).

Silvicultural control of mistletoe in the Pacific Northwest is possible in many developing stands, although complete eradication may need to await the next rotation. Two major alternatives have been found for dealing with the disease. First, if the crop trees in the understory are heavily infected, the stand is usually clearcut, the understory destroyed, and the site prepared and planted. Infected trees along the edge of the planted areas should be removed when the clearcutting is made or before planted trees are 3 ft (0.9 m). If adjoining trees cannot be removed, then an area extending about 100 ft (30.5 m) away from them into the plantation should be planted with a nonsusceptible species.

The second alternative, for moderatly infected stands, is to remove all overstory trees and thin the understory to not less than 15 x 15 ft (4.6 x 4.6 m). In stands with an average potential crop tree d.b.h. larger than 2 in (5 cm), priorities for crop-tree selection are:

- Uninfected dominants and codominants.
- Dominants and codominants with dwarf mistletoe restricted to the lower third of the live crown.
- Dominants and codominants with dwarf mistletoe restricted to less than 50 percent of the branches in the lower half of live crown.
- Intermediates with no visible infection.

All potential crop trees should have at least 25 percent of their total height in live, uninfected crown. Trees with dwarf mistletoe infection in the top fourth of live crown are questionably suitable as crop trees. Acceptable stocking should be selected from trees in the highest priority before selections are made from the next lower class.

Treatments in mistletoe-infected pine stands should create an even canopy. Single story stands are preferable to prevent infection of understories.

ROOT ROT

Armillaria root rot has been in the natural ponderosa pine forests of the Pacific Northwest for a long time (Roth et al. 1977). Recent observations show an increase in second-growth mortality. Much old-growth mortality also is caused by armillaria, especially near the transition zone with Douglas-fir.

Armillaria spreads vegetatively from tree to tree by root contacts or by black, string-like rhizomorphs. The fungus does not spread extensively by spores. In many forests, the sporophores are rarely found.

The best indicators of the disease are white mycelial fans between the bark and wood at groundline. These fans may not be visible in trees just beginning to turn color, or they may be gone from those dead for several years. Impressions of disintegrated fans sometimes remain visible in the inner bark of trees that have been dead for several years. Armillaria damage is often recognized in dense stands as pockets of dead saplings around old-growth stumps or large, nearly treeless openings with a few saplings in the center. Other root rots cause similar disease symptoms, so examination of the root collar for mycelial fans is required to confirm the cause as armillaria.

Roth et al. (1977) have suggested a method of treating seriously infected stands. Inoculum in the form of large roots and stumps is removed from the soil. Infection centers are located and tractors are used to remove stumps and roots of trees with symptoms plus those of adjacent trees without, to create a barrier between the disease foci and the healthy stand. Distance of stump and root removal into trees without symptoms adjacent to those with symptoms should increase as average stem diameter increases (Shaw 1974). Where trees showing disease of 5-, 9-, and 11-in (13-, 23-, and 28-cm) d.b.h. still retain some needles or twigs and bark is still intact, clearing should extend 15, 18, and 25 ft (4.6, 5.5, and 7.6 m), respectively, into healthy trees. Complete control is probably not possible. Some reserve trees may die after treatment, but growth in formerly infected areas will exceed mortality, and this margin should widen with time. Repeated application in future timber sales will further check the disease.

NEEDLE BLIGHT

Elytroderma needle blight is occasionally conspicuous in the forests of the Pacific Northwest. Although less destructive than its alarming appearance suggests, it has reduced growth rates on more than 100,000 acres (40 469 ha) in Oregon and Washington and locally has killed many trees on a few areas of severe infestation (Childs 1968a). From 1940 to 1950, more than 200 million fbm of sawtimber on the Ochoco National Forest had to be salvaged. Great loss has also occurred through premature cutting of diseased trees threatened with death. Outbreaks have been recorded since 1913.

Unlike typical foliage diseases, elytroderma needle blight often persists for several years. Persistence of the outbreaks can be explained. Elytroderma invades twigs and buds as well as needles, survives perennially in twigs, and spreads vegetatively into needle primordia (Sikorowski and Roth 1962). Once a damaging wave of infection has occurred, the fungus is not dependent on annually recurring periods of weather favorable for sporulation, germination, and host invasion to continue causing damage.

The most striking symptom of the disease is the reddish brown "flags" that appear in the spring. Infected needles of the preceding season's shoots stand out in striking red-brown contrast against the normal green foliage. As the season progresses, the red needles are partly hidden by the current year's growth. Later they defoliate. Symptoms vary from tree to tree. Some trees may be engulfed in blighting, but others may have only one branch with symptoms. Compact, pendent witches' brooms of hook-shaped branches are common in trees of high vigor and are thought to perpetuate the disease. Young seedlings are rarely infected (Roth 1959).

Without research on control, little can be done about the disease except to put young stands in thrifty condition, and to salvage threatened mature trees before they die. Where just a few scattered trees are dead or dying from the disease, they should be salvage-logged. Where the stand is substantially infected and repeated cuts at short intervals would raise logging costs, managers should: postpone salvage until heavy mortality is likely to occur, beetle populations are increasing rapidly, or the stand is due for logging; and then harvest all pine except those in a high-vigor class with no more than about 5 percent of the twigs flagged (Childs 1968a).

Where infection during the current outbreak has been light, the disease is unlikely to be seriously damaging in the future. At the other extreme, stagnated stands on and near former outbreak centers are likely to be damaged by another outbreak before they mature. In thinning young stands, Childs (1968a) recommended the following:

- Maintain good spacing. Avoid large openings.
- Select no crop trees flagged within 3 ft (0.9 m) and preferably none flagged within 6 ft (1.8 m) of the leader.
- Select uninfected or only lightly infected crop trees even at a considerable sacrifice of present tree size and quality.
- Do not be bluffed by the disease. Where good pine has grown, good pine will grow again.

Future outbreaks will undoubtedly cause some damage even in vigorous young, mature stands and more severe and rapid damage in decadent, overmature stands. For mature stands, Childs (1968a) suggested:

- Do not take hasty action.
- Evaluate the situation annually on the basis of examinations made in the spring and early summer.
- Revise logging plans to give higher priority to stands where appreciable damage is to be expected within the next few years and to provide for immediate logging wherever infection rates or beetle populations start to increase.
- When logging in lightly infected stands, remove the occasional tree that may be found with more than a third of its twigs flagged or killed; discriminate as much as is practicable against the most heavily infected of the other trees.
- When logging in moderately or heavily infected stands, either cut drastically, leaving only trees with very good, Keen class A or B+ (Keen 1943) crowns and no more than a few scattered flags, or plan to relog within a year or so if necessary. Partial cuts in diseased stands are usually followed by rapid crown deterioration and high mortality of residuals.

COMANDRA RUST

Comandra rust is present in some sapling and small pole stands. In unthinned stands, it is probably unimportant because it is scattered and seldom occurs in more than 5 percent of the stand. In thinned stands, the disease may cause substantial damage. Spores of the fungus are often concealed under bark scales; branch swellings disappear as branches die and drop to the ground, and infected trunks are seldom noticeably swollen. Consequently, thinning crews miss many of the infected trees--leaving a high rate of infection in the crop trees (Childs 1968b).

In mature stands in early stages, the disease is an immediate threat only if infection enters the trunk below midcrown; this is not very common even in young, mature trees and is rare in old growth.

This rust does not spread directly from tree to tree; its alternate host is common comandra. Control by eradication of the alternate host is not practical.

Mature trees obviously infected with the disease should gradually be harvested; the greatest gain in reducing the prevalence of the disease is by removing diseased trees in thinning young stands.

OTHER DISEASES

Annosus root rot can be found in many Pacific Northwest ponderosa pine stands. The disease is almost always associated with earlier cutting operations. The spores of the fungus germinate on freshly exposed stumpwood. The fungus can colonize in stumps and spread vegetatively to surrounding trees along roots. Centers of infection show up as dead seedlings and saplings surrounding large stumps (Russell et al. 1973). The fungus produces small leatherly conks with a tan upper surface and creamy lower surface. These conks are found in the duff on root collars of recently killed trees.

Annosus root rot is not yet serious in this region, but it is increasing; cutting favors it. Infection can be prevented by covering fresh cut stumps with borax. This treatment is registerd with EPA, but is not presently being recommended for use in commercial stands because of the low incidence of disease.

Western gall rust is found on ponderosa pine (Peterson 1960). The rust does not require an alternate host but spreads directly from pine to pine. It causes woody galls on stems and branches; seedlings and saplings may be killed by the disease, but larger trees rarely suffer mortality. Galls on larger trees enlarge with age and cause deformities that reduce lumber quality. No direct control is available. Infected trees, particularly those with stem galls should be removed in precommercial thinning. Cones should not be collected from trees with numerous infections, because some field indications of genetic resistance have been found.

Insects

MOUNTAIN PINE BEETLE

Tree killing by mountain pine beetle, has increased with conversion of old-growth stands to second growth, and this problem seems destined to intensify as more young stands attain susceptible size (Sartwell 1971). Severe infestations in ponderosa pine occur mainly in pure, even-aged stands of poletimber about 50 to 100 years old (Sartwell and Stevens 1975).

Infested trees are first recognized by pitch tubes on their trunks and red boring dust in bark crevices. Later, foliage discolors to greenish yellow and then to reddish brown (Furniss and Carolin 1977). Adult beetles are rather stout, cylindrical, and black, 0.16 to 0.29 in (4 to 7 mm) long. Egg galleries are perpendicular, long, and engraved on both sapwood and inner bark (fig. 3).



In low populations, beetles tend to attack the weakest trees. Fewer than five trees/acre (12/ha) per year are killed, and they occur singly. During outbreaks, which usually last for several years, trees of all crown classes are killed, but dominants and codominants suffer most. The beginning of an outbreak is marked by the clumping of tree mortality in groups of three or more trees. That 1st year, about 5 to 10 trees/acre (12 to 24/ha) are killed. Beetles of subsequent generations expand the clumps, creating holes in stands so large that entry of a new age class of trees is required for full stocking. Peak tree mortality usually occurs about the 5th year of an outbreak, when 50 to 150 trees/acre (123 to 371/ha) are killed. Thereafter, the outbreak declines and usually subsides by about the 8th year. Commonly, an outbreak of mountain pine beetle in ponderosa pine results in death of about half the trees and loss of about two-thirds of the stem basal area.

Figure 3.--Egg galleries of the mountain pine beetle.

High stand density is a consistent characteristic of second-growth ponderosa pine stands severely infested by this insect. Intense between-tree competition at high stand densities is believed to reduce vigor of even the largest trees and, thus, to be the underlying factor in the occurrence of beetle outbreaks (Sartwell and Stevens 1975).

Thinning now appears to be one way of controlling outbreaks in pole-sized ponderosa pine (Sartwell and Dolph 1976). In eastern Oregon, two studies suggest that thinning to recommended basal area levels compatible with most management goals (see stocking level curves, fig. 22) will greatly reduce the incidence of tree killing. Recommended treatment would be thinning to a density well below the maximum stocking level curve, such as 70 to 80 ft^2 of basal area per acre (16 to 18 m^2/ha). This should "bug proof" the stand until the first commercial entry is made. Preferably, stands should be thinned well before any beetle activity is evident.

Spraying infested trees without reducing stand density provides only temporary relief--5 years or less. Thinning of dense stands is presently thought to be the forest manager's first line of defense against mountain pine beetle in northwest stands of ponderosa pine.

PINE ENGRAVER

The pine engraver occurs naturally in all ponderosa pine stands (Dolph 1971 and fig. 4). Individual trees and stands are periodically attacked. Any thinning will attract pine engravers; however, they usually confine their attack to the slash. In "Ips years" that are associated with drought, they may attack both residual trees in thinned areas and nearby unthinned, stagnated stands.

Usually two to three generations a year are produced, depending on climatic conditions. Adults overwinter in the upper few centimeters of soil and litter under the slash from which they emerged or at the base of brood trees. Some may overwinter under the bark of stumps, or dead trees or on the undersides of large pieces of logging slash. The first attack in the spring usually occurs in April or May. These overwintering beetles seldom attack green, healthy trees but prefer weakened trees and thinning slash that was cut the previous fall and early winter. The second flight occurs in late July and August. Slash in which the broods developed is usually too dry for reentry so beetles move to fresh slash. Mating takes place, and broods develop, but this generation of beetles usually drops to the ground for hibernation. Occasionally, a third generation develops when climatic and environmental conditions are ideal. The second flight causes most of the tree mortality. Slash from stands logged or thinned between February and July are most receptive to invasion.

A



Figure 4.--Trees killed by the pine engraver, A, and breeding galleries of the insect, B.

B



Direct control is usually impractical. The present approach is to keep stands healthy. On small ownerships, thinning between August and February is safe, or slash should be disposed of before it is attacked. On large ownerships where thousands of acres are thinned each year, managers should keep enough slash available so that beetles move from one supply of slash to another. Occasionally, a residual tree is lost but overall mortality is usually not serious.

Heat generated under the bark by direct sunlight causes most of the brood mortality in slash of small diameter. Loss of valuable trees in campgrounds occurs when fuel wood infested with Ips is piled against trees in shaded moist locations. Insect broods develop, and emerge in great numbers; some are likely to attack the adjacent tree and kill it. Stacked green wood in a shaded area often provides an ideal incubator for the development of massive hordes of Ips.

WESTERN PINE BEETLE

No other insect that attacks ponderosa pine has had such an impact on the species. During the drought years of the 1930's, losses from

western pine beetle, were so heavy that many foresters thought pine stands in the Pacific Northwest were doomed. Entomologists discovered, however, that they could identify high-risk trees. Not only were these the trees that were the most likely to be killed, but they were also the ones that produced more beetles to move on to other trees. Consequently, harvest of these trees tended to protect the rest of the stand.

Periodic salvage sales that harvest trees that have been attacked or are likely to be attacked are necessary to keep beetle numbers manageable. Normally, this insect breeds in a few overmature trees, windfalls, unhealthy trees, or in trees weakened by drought, stand stagnation, or fire (Keen 1952). Under outbreak conditions, it will kill trees of all ages, although trees under 6 in (15 cm) in diameter are seldom attacked. Frequently, this beetle attacks trees jointly with other insects such as the pine engraver in the top, mountain pine beetle in the midbole, or the turpentine beetle, at the base.



The top-killing associates may attack first, thus providing favorable breeding for the western pine beetle (Furniss and Carolin 1977). Their tunnel design is distinguished from other bark beetles by the winding egg galleries that cross and recross each other (fig. 5). Attacks start in late spring and early summer and continue until cold weather.

Figure 5.--Western pine beetle egg galleries on ponderosa pine.

WESTERN PINE SHOOT BORER

The western pine shoot borer has been recognized within the last decade as a notable threat to achieving intended growth in some second-growth and planted stands of ponderosa pine (Stoszek 1973). A recent survey with attractant-baited traps revealed that this insect is common throughout ponderosa pine stands of the Pacific Northwest, in many places as abundant as in southern Oregon where it is known to be a serious pest of plantations.[2/]

Damage is often not apparent, and evidence of infestation is obscure to the untrained eye. Symptoms are visible in summer once pine-shoot elongation and needle growth are completed; the most apparent are a disproportionally increased density of needle fascicles and substantially stunted needles on the highest portion of the shoot. The "shaving brush" appearance is a reliable sign of infestation compared to the uniform needle length of an uninfected terminal (fig. 6). A disproportionate ratio of terminal to lateral shoot is another sign of infestation. The feeding tunnel confined to the pith is straight and filled with compacted frass and resin.



Figure 6.--Typical stunted terminal caused by western pine shoot borer.

Not all shoot distortions, however, are caused by the shoot borer; similar symptoms may be caused by abnormalities in bud setting.

Stoszek (1973), working in south central Oregon, concluded that loss in average annual height increment could be up to 25 percent. Surveys of pine plantations indicated increased incidence of infested leaders on drier sites.

So far, control for pine shoot borer has not been developed. Systematic insecticides have performed poorly in field trials. Control by mating disruption with synthetic sex attractants is highly promising, however. This approach requires release of attractants in such amounts that male moths cannot locate females. The insect is now recognized as a threat to intensive forestry in the pine lands of the Pacific Northwest, and researchers are determining if confusion techniques will give acceptable control. They are also testing other methods of suppression.

[2/]Manuscript in preparation, "Distribution and hosts of Eucosma sonomana in the Western United States as determined with pheromone-baited traps," by Charles Sartwell, G. E. Daterman, T. W. Koerber, R. E. Stevens, and L. L. Sower.

TURPENTINE BEETLE

The turpentine beetle is widespread throughout the Pacific Northwest. Although commonly observed in dying trees, it is usually not the direct cause of pine mortality. The beetle attacks trees that have been weakened by lightning, fire, drought, flooding, or other insects.

Even when the beetles appear in a stand, their effect on the trees may be only temporary. Large, reddish pitch tubes are formed at the point of attack and are usually located on the lower 6 ft (1.8 m) of the bole. Beetles excavate short, irregular, cave-like egg galleries between the bark and the wood (fig. 7). Eggs are laid in groups at intervals along the sides. The larvae feed out through the inner bark in mass formation, forming a cavity that can be a few square inches or a square foot or more between the bark and the wood.

The beetle is seldom important in commercial timber stands. If control becomes necessary in parks or campgrounds to preserve individual trees, the damage can be stopped by cutting out the attacking beetles where pitch indicates their presence, or by chemical spray or screening the lower bole during the flight period (Furniss and Carolin 1977).

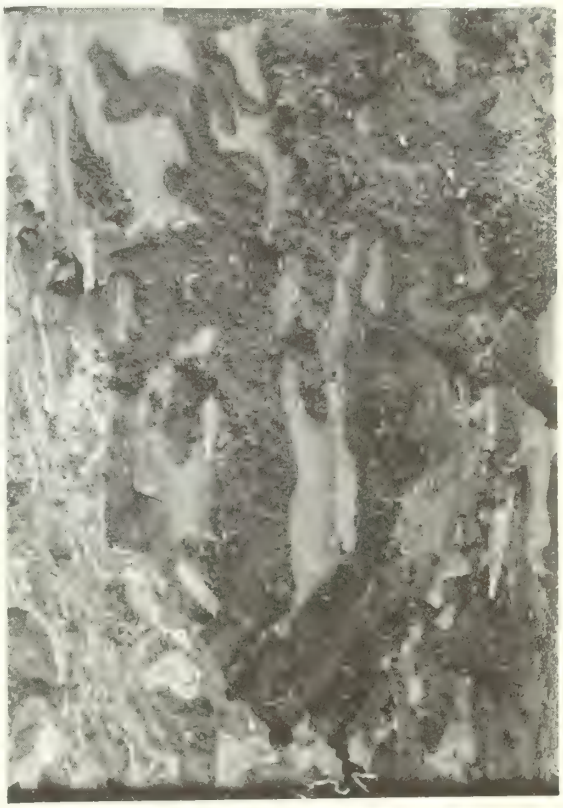


Figure 7.--Galleries of the turpentine beetle.

PINE BUTTERFLY

The pine butterfly is potentially one of the most dangerous enemies of ponderosa pine in the Pacific Northwest (Keen 1952). Some devastating attacks were reported at the turn of the century and in the early 1920's. Defoliation by this insect predisposes pines to attacks by western pine beetle. Pine butterfly has apparently been held in check recently by a natural enemy, the parasitic wasp Theronia atalantae (Poda), and by environmental conditions. Past outbreaks have seldom lasted more than 3 or 4 years before the parasite has the butterfly under control. Tremendous amounts of timber may be lost, however, before the natural enemy has subdued the outbreak.

The adult is a white butterfly with black markings and a wing width of about 1-3/4 in (4.4 cm), generally similar to the cabbage butterfly (fig. 8). Flight occurs in August through October. Emerald green eggs are laid in rows, attached to needles in the tops of trees. The eggs pass

A B



Figure 8.--Pine butterfly: A, adult; B, ponderosa pine branch defoliated by the pine butterfly.

through winter and hatch in June. The caterpillars feed on the needles in the spring, and then the full-grown larvae drop to low-growing vegetation by silken threads and form pupae. In 15 to 20 days, the insects emerge as butterflies, with usually only one generation a year.

Mammals and Birds

POCKET GOPHERS

Pocket gophers are a serious threat to the regeneration of our pine lands. These mammals kill or slow the growth of pine seedlings by cutting or gnawing off roots and debarking main stems of seedlings (fig. 9). In 1970, Barnes (1973) recognized the notable impact pocket gophers had on both ponderosa and lodgepole pine in eastern Oregon and Washington. The problem appears to be accelerating because of intensified forest management, and managers are becoming more aware of gopher damage (Capp 1976). Postponement of final harvest cutting is sometimes being recommended because of the inability to prevent regeneration losses to gophers.



Figure 9.--Planted ponderosa pine, about 3 ft (0.9 m) high, girdled by pocket gophers during the winter, under a 2-ft (0.6-m) snowpack.

Numbers and distribution of pocket gophers are rapidly expanding because forest disturbance generally improves habitat for them. Logging overstory trees encourages herbaceous vegetation (McConnell and Smith 1970), the preferred forage of gophers. Young gophers, after they are weaned and excluded from the parental burrow system, disperse and seek favorable habitat to build their own burrows. This dispersal mechanism allows gophers to establish populations quickly in new habitat. Ditches of road rights-of-way, stream drainages, and natural meadows also support gophers and promote distribution of animals from one silvicultural treatment area to another.

Present control methods are not adequately reducing seedling loss to gophers. These methods, primarily aimed at population reduction by trapping and machine application of toxic grain, are often ineffective because of limitations in operational programs and problems inherent in direct population control (Barnes 1973). Successful protection of tree seedlings has not been well documented despite treatment of tens-of-thousands of acres w toxic baits (Crouch and Hafenstein 1977).

Reducing the required food supply of the gopher is another approach to the reforestation problem, but present information limits application to only a few forest communities. Crouch and Hafenstein (1977) improved survival of planted ponderosa pines by reducing the competition to seedlings from herbaceous vegetation and predation by pocket gophers. Other workers (Howard and Childs 1959, Keith et al. 1959, Hull 1971, and Christensen et al. 1974) report similar relations between herbaceous vegetation and pocket gopher populations.

A promising new development is a seedling protector that provides both above- and below-ground protection (Anthony et al. 1978). It is a cylinder of plastic netting that gradually decomposes in sunlight, and the rate of decomposition can be varied by the chemical composition of the netting. Netting currently being tested requires from 4 to 10 years to decompose by ultraviolet radiation; no known environmental hazards are associated with the plastic or its byproducts (Campbell and Evans 1975).

Grouping plant communities according to the incidence of gophers in natural and disturbed stands and their potential for gopher occupancy after disturbance is another approach to controlling gophers. We may be able to alter silvicultural techniques so that ideal gopher habitat is not created (Volland 1974). Barnes (1974) suggested leaving uncut buffer strips between logged units and gopher populated areas, direct control before harvest where a reservoir of animals occurs within a proposed logging unit use of site preparation techniques that disturb the soil and vegetation as little as possible, and selective cutting in certain communities. Barnes also emphasized the importance of extensive, on-the-ground reconnaissance to assess gopher populations before silvicultural practices are initiated.

DEER

Mule deer are a concern to reforestation on pine lands of the Pacific Northwest, but the appeal of these animals outweighs their pestiferous side. Although deer feed on natural conifer seedlings, their undesirable interactions with reforestation usually consist of browsing damage in plantations that lie along migration routes to winter ranges (Crouch 1976). Damage depends on the number of deer, weather in the fall and spring and its influence on speed of migration, and the amount and duration of snow cover.

Browsing of planted ponderosa pine can quickly reduce stocking to unacceptable levels, especially where the site is marginal for survival of planted seedlings. Damage on summer range is frequently minimal. Browsing control usually consists of chemical repellents, cages for individual trees, and exclosure fences. Effectiveness is directly proportional to effort expended.

To assess a potential deer problem, a carefully prepared analysis of the site should be made before planting and the following questions answered:

- Is the site marginal for ponderosa pine?
- Is the site in a migratory route?
- Is the site a winter range for deer?

If the answer to any one or more of these questions is yes, then a browsing problem probably exists, and an economic analysis of the control options mentioned above should be made.

In considering chemical deterrents to mule deer browsing, remember that most mule deer browse in the fall, winter, and spring on areas adjacent to winter ranges and on migratory routes. Some damage occurs on summer range, but this is usually minimal. Time of application is important; most repellents for mule deer are applied to individual trees in the fall. Success in preventing browsing varies. Some wildlife specialists believe that the chemical deterrents popular now will not be available in a few years. TMTD (tetramethylthiuram disulfide) and BGR (big game repellent) are federally registered for protecting conifer seedlings from deer browsing. TMTD is usually sprayed on seedlings in the nursery before lifting, but can be applied by hand dipping. Limited success is reported in deterring deer and elk. BGR should be applied to dormant seedlings before bud burst. The active ingredient in BGR is putrified liquid egg. Results of recent tests are promising (Rochelle et al. 1974).

PORCUPINES

Inner bark and foliage of ponderosa pine serve as winter food for porcupines. Death of trees by girdling is not uncommon; more typically, the top of the tree is girdled and dies.

Porcupines are largely nocturnal and ordinarily spend days in a rest tree or den in a rock outcropping. Active rest trees and dens can be identified by broken quills, accumulated droppings, and the odor of urine. In spring, the young are born in these rock dens--one young per female--but juenile mortality can be extremely low and numbers can increase rapidly in a few years.

Porcupines do not hibernate, and are active throughout the winter when ponderosa pine is their preferred food. During the summer, 85 percent of porcupine food is ground vegetation (Lawrence 1957), with the rest from trees. Ponderosa pine infected with dwarf mistletoe is often subject to heavy damage.

Cougars, bobcats, and fishers are predators of the procupine; they attack and kill porcupines in trees as well as on the ground, flipping the porcupine over to expose the unprotected belly. These animals should not be considered as a sole means of porcupine control because prey-predator relations are generally complex and because of the habits of these predators.

Logging of mature pine stands and thinning the understory stimulates development of ground vegetation and improves habitat for porcupines. Human activity has created an environment much more favorable for porcupines than existed under pristine conditions, which is why porcupines can be a problem if their numbers are left unchecked.

Hunting appears to be the most effective way to deal with large populations covering vast areas or small localized concentrations. In summer and early fall, animals tend to congregate in meadows, irrigated crop lands, cutover areas, and road edges. Road hunting in the early evening can be effective in summer. Winter hunting in concentrated areas is effective, especially after a storm when animals can be tracked easily.

Keeping resident populations to a reasonable level appears to be the answer to control of tree damage. Periodic reporting of animal activity b field personnel would help.

OTHER ANIMALS

Small rodents, principally red squirrels, deermice, golden-mantled ground squirrels, and chipmunks destroy ponderosa pine seed and seedlings. Voles also may destroy newly germinated or planted seedlings, but they are not considered seed eaters. Small mammals are generally not considered a major obstacle to pine regeneration except in occasional localized situations.

Birds consume many seeds, mostly in flocks that move from area to area during migration. Seed-eating usually starts in early September when the cones begin to open. Pinon and Steller's jays, are commonly seen picking seed from partially opened cones of ponderosa pine. The white-headed woodpecker, often destroys much seed in cones still on the tree. Other important seed eaters are the mourning dove, mountain chickadee, common flicker and dark-eyed junco.

any birds feed on harmful forest insects, however, so that the bene-
sfrom birds usually outweigh the harm. Some silviculturists believe
ttiming seed crops and site preparation so that adequate seed is mixed
hthe soil, out of reach of birds and mammals, will increase the number
srviving seedlings.

bst managers do not consider the available measures to control seed
es to be practical.

ECOLOGY AND SILVICULTURE

Compatible Philosophy

A basic appreciation and understanding of ecology in the ponderosa pine
e.s important because of its significance in influencing silvicultural
ctice. Spurr and Barnes (1973) concluded that the silviculturist should
k to understand ecological principles and natural tendencies as they
at to trees and forest communities with which they work.

Forest managers in the Pacific Northwest have become increasingly aware
plant and animal reactions to human activity. During the last three
ads, ecologists in the Northwest have found that certain ecological
divisions are much more sensitive to such activity than others. Thus,
understanding of the ecological subdivision and its composition is ad-
ale before a management prescription for the land and its resource is
mended. To make the management prescription functional, we must first
arte these ecological subdivisions so they may be recognized in the
ld and identified on a map.

Ponderosa Pine Plant Communities

We are fortunate that many ponderosa pine community types or associ-
on have been identified and described throughout the Pacific North-
t. What happens to these associations under various silvicultural
atents must be observed and recorded, so we can eventually predict with
scable certainty what will happen to each plant community under each
viultural prescription.

Geologic province	Area	Approximate number of ponderosa pine communities described	Author
Blue Mountains	Eastern Oregon, southeastern Washington	7	Hall (1973)
High Lava Plains	Central Oregon pumice zone	14	Volland (19
Basin and Range	South central Oregon	7	Hopkins (1979a, 19
Basin and Range	South central Oregon	5	Dyrness (19
Basin and Range	South central Oregon (Silver Lake deer range)	7	Dealy (197
Okanogan Highlands Columbia Basin	Eastern Washington	6	Daubenmire and Daubenmire (1968)

The first three authors provided an ecological basis for management guidelines on range conditions and trends, tree stocking, silviculture, succession trends, and vegetative mapping. Eventually all National Forest land in the Pacific Northwest will be described in such a way to aid in making silvicultural prescriptions.

Other workers, such as Dealy (1971), have provided suggestions for the silvicultural manipulation of ponderosa pine communities to preserve the continued well-being of a particular wildlife habitat.

Following is a partial list of ponderosa pine associations that have detailed descriptions available, along with recommendations for management. The most abundant tree, shrub, and herbaceous species across all stands representing the community are used in the nomenclature. A slash (/) separates species of different life forms, and a dash (--) separates those of similar life form.

Blue Mountains Province (Hall 1973)

Ponderosa pine/wheatgrass
Ponderosa pine/fescue
Ponderosa pine/bitterbrush/Ross sedge
Ponderosa pine/blue wildrye
Ponderosa pine--Douglas-fir/elk sedge
Ponderosa pine--Douglas-fir/snowberry/oceanspray
Ponderosa pine--Douglas-fir/ninebark

High Lava Plains Province (Volland 1976)

Ponderosa pine/bitterbrush/bunchgrass
Ponderosa pine/bitterbrush/squirreltail (on Rhyolite)
Ponderosa pine/bitterbrush-sagebrush/squirreltail (on Rhyolite)
Ponderosa pine/bitterbrush-sagebrush/fescue
Ponderosa pine/bitterbrush/fescue
Ponderosa pine/bitterbrush-manzanita/fescue
Ponderosa pine/bitterbrush-snowbrush/fescue
Ponderosa pine/bitterbrush/needlegrass
Ponderosa pine/bitterbrush-manzanita/needlegrass
Ponderosa pine/bitterbrush-snowbrush/needlegrass
Ponderosa pine/bitterbrush/sedge (fig. 10)
Ponderosa pine/bitterbrush-manzanita/sedge
Ponderosa pine/bitterbrush-snowbrush/sedge
Ponderosa pine/sedge-fescue-peavine

A great deal of ecological information has been gathered in recent years that can help silviculturists write prescriptions for specific ponderosa pine associations.



Figure 10.--Ponderosa pine/bitterbrush/sedge plant community. Pine reproduction frequently is absent or sparse.

SILVICULTURE AND MANAGEMENT

Planning and Decisionmaking

A well-conceived land-use plan and a firm long-term management objective and commitment are essential to sound silvicultural prescriptions. Once a stand prescription is implemented, judgments have been made that are often irreversible. Thus, one vital element of successful silviculture is planning.

In meeting management objectives, the silvicultural prescription usually must be varied to meet the particular ecological limitations of the plant community, especially regeneration risks and recognized environmental constraints. Next, management and the silviculturist should agree upon objectives, particularly a priority listing of land uses and the mix of products and expected services, along with monetary returns.

The prescription should address silvicultural systems--effects of various rotation ages, reentry schedules, and stand densities--as they affect the ability to achieve all resource-management objectives. The prescription may include alternatives, because seldom is only one prescription acceptable. Usually the prescription unit is not less than 10 acres (4 ha), although it could cover several small segments that accumulate to much larger tracts. Treatments for the readily identifiable segments may have small differences in initial entries, but they may be made more homogeneous for second-entry treatments.

Land-use planning followed by the implementation of silvicultural prescriptions is relatively new in the pine type, both on public and private lands. These prescriptions should stand the test of time, and they should not be altered arbitrarily to meet allowable-cut demands. Long-term goals for the forest as a unit should be kept intact for the benefit of future generations.

The stand is the unit that is singled out, looked at, measured, and designated for silvicultural treatment. By definition, it is a group of trees sufficiently uniform in species, age classes, and condition to be a homogeneous, distinguishable, manageable unit. Because of past cutting practices in the Pacific Northwest, the manageable ponderosa pine stand is often difficult to recognize. The forest may be a mosaic of even-aged, small groups of immature and mature trees with a scattered understory of reproduction. This frequently calls for redefining the term stand. The boundaries of the manageable unit may be enlarged or reduced, but this flexibility must be reflected in the objectives written into the stand treatment prescription.

Even Aged or Uneven Aged

Rather than professing that even- or uneven-aged management is best for ponderosa pine, we should keep in mind that both methods can be used successfully. This is fortunate because environmental constraints often urge managers of public land into the uneven-aged regime although even-aged is often easier to implement. Actually, no well-documented research in the region shows one form superior over the other, but mature or larger trees have been shown (Barrett 1969) to exert a significant effect on smaller understory trees in both height and diameter growth. This seems to indicate that uneven-aged pine forests will need to be managed with low density to permit younger or smaller trees, which ultimately replace the larger ones, to grow at a reasonable rate. Uneven-aged management cannot be assumed an easy and inexpensive resolution to all other resource conflicts within the pine forests. To be successful, it will require expertise by the silviculturist and possibly expensive stocking-level control throughout all size classes of the structure visualized.

The reason some stands are maintained in uneven-aged management is simply that the lands came that way. An abrupt change to an even-aged regime now would require cutting too many small, young trees prematurely. Similarly, many public forests were acquired through land exchanges with private lumber companies after the merchantable or high-value trees were harvested. The emerging forests were often even aged. Therefore, the management regime on much of the land was decided many years ago by economics, fire, or other natural events.

On public lands, the extent of even-aged management often is limited by environmental constraints. On industrial lands, most ponderosa pine acreages are being converted to even-aged stands and intensively managed for the highest possible yields.

Treatments

COMPLETE OVERSTORY REMOVAL

Probably the most common stand treatment in the pine type today is the orderly conversion of old, mature stands to vigorous second growth. Most stands consist of a mature overstory with a suppressed understory of seedlings or older saplings. Harvesting the overstory and saving the understory resembles the final removal stage of the classic shelterwood silvicultural system. Often the stand conversion results in a four-fold increase in current annual increment rate within a decade, if existing understories can be preserved and used in the next rotation (Barrett 1973). Stands that are likely to suffer heavy mortality, or that are below minimum stocking standards but contain usable understory trees, are given cutting priority[3/] as follows:

[3/]From U.S. Department of Agriculture. 1974. Silvicultural examination and prescription handbook. Region 6, For. Serv., Portland, Oreg.

1st Lightly Stocked Damaged Overstory With Established Understory. Crop-tree stocking is at or above recommended level and at least 4-1/2 ft (1.4 m) tall, but less than pole size. The mature overstory is below minimum stocking level, and trees are in poor condition.

2d Lightly Stocked Healthy Overstory With Established Understory. Crop-tree stocking is at or above recommended level and at least 4-1/2 ft (1.4 m) tall, but less than pole size. The mature, healthy overstory is below minimum stocking level.

3d Lightly Stocked Poor Vigor Overstory With Pole Understory. Crop-tree stocking is above minimum, and crop trees are pole size. Mature trees are below minimum stocking level, are of poor thrift, and will likely die before the stand is scheduled for a regeneration cut.

4th Lightly Stocked Poor Vigor Overstory With Commercial-Thinning-Size Understory. Crop-tree stocking is above minimum, and crop trees are of merchantable size. Mature trees are below minimum stocking level and of poor thrift. Evaluate whether mature trees will survive until a regeneration cut is scheduled for the crop trees. If mature trees will last, do not schedule overstory removal.

5th Lightly Stocked Overstory With Above Minimum Stocking Understory. Crop-tree stocking is below the recommended level but above minimum, and crop trees are at least 4-1/2 ft (1.4 m) tall but less than pole size. The mature overstory is below minimum stocking level, and trees are not needed for seed.

In using these guides, note that the minimum stocking curve shows that a stand of 30 trees, 18 in (46 cm) in diameter or more, constitutes adequate minimum stocking. Sometimes healthy, vigorous overstory stands on higher sites, with slightly fewer trees, grow impressive amounts of wood and should be given low priority for cutting. Careful examination of overstory vigor and growth is necessary before you decide to cut the stand because it is below stocking. Also, strict application of the priority system may result in concentrating the cut in one locale, which may not be advisable. Most ponderosa pine understories are uneven aged but essentially one size-class and are therefore considered even aged for prescription purposes.

SANITATION SALVAGE

Although sanitation salvage cutting (Sowder 1951) as a stand-treatment practice is gradually diminishing, it is still a necessary element of stand management throughout the Pacific Northwest ponderosa pine type. Large acreages of mature timber still exist, and low vigor trees within these stands are subject to attack by insects and disease. Dying trees or trees likely to die in the next few years should be harvested soon after symptoms appear. The need for salvage cutting frequently coincides with drought; when trees are under severe moisture stress, they succumb easily to beetle attack. The two main tree-classification systems used in sanitation salvage cutting are Keen's (1943), discussed in detail later in this paper, and Salman and Bongberg (1942).

Stands continually sanitized for many years frequently show serious depletion of growing stock. Repeated entry without using established skid trails kills reproduction that is growing stock for the next rotation. For this reason, sanitation salvage sometimes keeps pine managers from moving rapidly into intensive management, probably resulting in a loss of production.

REGENERATION HARVESTS

There comes a time in the life of every forest stand when it must be reproduced. Aside from State laws requiring successful and prompt regeneration, no land manager today can afford idle forest land. Successful reforestation is the first important step in a program of intensive forestry.

Two choices for regeneration are available--natural or artificial. Natural regeneration is the renewal of a tree crop by tree- and wind-sown seed; artificial regeneration is the renewal of a tree crop by direct seeding or planting. Obtaining reproduction by natural seedfall under any silvicultural system is usually highly unpredictable on most lower elevation ponderosa pine sites in the region. Many managers plant directly after regeneration cutting, regardless of the silvicultural system, to prevent the site from being taken over by competing vegetation.

In choosing areas for regeneration cutting, you should follow a systematic process so that areas most in need of treatment are dealt with first. Such a priority system (see footnote 3), based on stand characteristics, follows:

1st Mature Stands--Poorly Stocked. The number of merchantable live, sound trees and crop-tree stocking are below minimum. This includes areas where stocking has been reduced by blowdown, disease, heavy defect, fire kill, and factors that cause the stand to exhibit poor growth because stocking levels of desirable species are below minimum.

2d Immature Stands--Poorly Stocked. Merchantable volume is present, the crop-tree stocking level is below minimum, and the stand is not likely to grow to an acceptable level within a reasonable time. This might include areas of manageable size with disease, blowdown, fire kill, storm damage, other defect, offsite plantations, and other areas exhibiting poor growth as a result of stocking below minimum.

3d Mature Stands--Defective or Damaged. The merchantable live, sound, crop-tree stocking level is above minimum, but the stand exhibits poor growth because of much defect and disease or blowdown. The stand is in danger of falling below minimum stocking from continuing insect attacks, disease, or blowdown.

4th Immature Stands--Poor Growth. Merchantable volume is present, and the live, sound, crop-tree stocking level is above minimum; but growth is unacceptable because of tree characteristics--such as low crown density, crown ratio, or other indicators of poor tree vigor--demonstrate that the stand would not benefit from stocking control; the stand is definitely offsite with low volumes; or there is a large amount of defect, disease, or other problems.

5th Mature Stands--Good Condition. The merchantable live, sound, crop-tree stocking level is above minimum, and the stand is still healthy. These stands should be considered for regeneration cutting last.

The two most common regeneration cutting methods used are shelterwood nd clearcutting. The selection system is used extensively to preserve the atural beauty of roadside strips, scenic vistas, and recreation areas. he shelterwood method is frequently used at higher elevation where the robability of windthrow is low and seedling establishment is high.

Shelterwood.--The shelterwood method gradually removes the entire stand n a series of cuttings toward the end of the rotation. It is designed to roduce even-aged stands. Many of the stands in the region are naturally ccurring shelterwoods where the reproduction has been in existence for 10 o 80 years. The shelter often consists of 10 to 40 mature trees per acre 25 to 100/ha) that are the seed source for reproduction. The overstory rees are harvested in one to three separate cuts over 3 to 5 years or more.

Recent experiments, however, have suggested that heavy volumes of overstory may be carefully removed in a single timber sale and still leave adequate stocking (Barrett et al. 1976). In areas that are difficult to regenerate, saving the existing understory is considered preferable to destroying the understory and starting from seed or nursery stock.

In other areas where the understory is poorly stocked and new reproduction is needed, a one- or two-cut shelterwood sometimes may be successful. The first cut should be made during or directly after a good seedfall. Cut trees should be selected from below, leaving 10 to 15 (25 to 37/ha) of the best-formed trees per acre (fig. 11). Piling and burning the logging slash directly after seedfall has aided in seedling establishment on several experimental sites, apparently because seed becomes thoroughly mixed into the soil. Damage to seedlings has been reduced by harvesting the shelterwood trees when seedlings are only about 12 inches (30.5 cm) tall and after an 18 inch (45.7 cm) snowfall. Managers, concerned about the unpredictability of obtaining natural reproduction, sometimes choose to supplement the natural reproduction by spring planting at least the minimum recommended number of trees under the shelterwood.



Figure 11.--A shelterwood created during a good seed year. Abundant seedlings were observed the folowing year, but numbers gradually diminished to several hundred per acre four growing seasons later. Developing snowbrush may offer severe competition to remaining seedlings. Some managers prefer to plant under the shelterwood to be assured of adequate stocking before brush takes over the site.

Clearcutting.--In this method, all trees in the area--large and small--are cut, which leads to establishment of an even-age high forest. On public lands, the method is used with discretion in the ponderosa pine type. Some industrial silviculturists, however, have used the system extensively in south-central Oregon. Large areas have been clearcut, the slash windrowed, and burned, and the area planted.

On public lands, the method is used in treating areas heavily infected with dwarf mistletoe. These clearcuttings are usually confined to less than 20 acres (8 ha), and the land is planted immediately after harvest--before competitive vegetation develops.

Selection.--The selection system aims to create uneven-aged stands and is used for their continual regeneration. When cutting first began in this type on public lands, it approximated a heavy grade of selection cutting and evolved into tree selection or group selection. From this, gradually evolved the system of partial cutting that left 15 to 30 percent of the merchantable volume for accelerated increment and a source of seed. Meyer (1934) predicted that this method of cutting would eventually eliminate the older age classes, leaving the younger ones, and end in a transition to even-aged stands. On many public and private lands, the next entry will convert large acreages to essentially even-aged stands.

To maintain uneven-aged stands, cutting in lower, submerchantable size classes is frequently necessary to stimulate growth of different aged trees. This practice, although necessary for perpetuating the uneven-aged regime, is questionable for producing optimum yield.

Seed Tree.--This method seeded many industrially held lands in the early days of logging ponderosa pine. The seed trees left, however, were often the smaller nonmerchantable or poorly formed trees. The slash was burned and the seedbed was often bare mineral soil or ash. Some lands were profusely regenerated, but large acreages were not, and they reverted to unproductive brush fields.

The "text book" seed-tree method has not been used to any great extent because too few trees are left to seed the areas adequately. A light shelterwood is preferred to the two to four trees per acre (5 to 10/ha) commonly left with the seed-tree method.

Artifical Regeneration

GENETIC CONSIDERATIONS

Planting and seeding presents an opportunity to preserve the genetic quality of the original stand, to improve upon it, or to lower the capacity to produce the desired volume or quality of wood. Because the stand will probably exist for many decades, a well-chosen genetic background is obviously important. Seed or seedling stock should be carefully chosen from

a reputable nursery that buys or collects certified seed from known locales and elevations. The few existing offsite plantations are visible reminders of the disadvantages of planting poor nursery stock.

The most promising step forward in ponderosa pine seed collection on public lands and some private lands in the Pacific Northwest has been the "plus-tree program." Briefly it consists of selecting outstanding trees in the forest, called "good phenotypes;" that is, the effects of the tree's environment and its genetic constitution have produced a good outward appearance, according to an objective scoring system. The goal of the program is to increase the rate of volume growth per acre. Trees are selected on their past diameter and height growth compared to other trees in the stand. Other characteristics--such as limb size, taper, and crown--are also considered. A portion of the seed from each tree is nursery planted, then outplanted, and evaluated. Although the plus-tree program is well underway in many areas, it frequently can not supply enough seed for fullscale nursery production. Seed must be collected in the usual manner, keeping in mind the following:

- The altitude of seed sources is one of the most important factors in a selective breeding program (Wang 1977).
- Ponderosa pine has genetic differences in cold resistance, growth initiation, growth rate, tree form, needle characteristics, and wood properties (Wang 1977).
- At this stage in our tree improvement program, use seed for regeneration within the zone where it was collected until it is proved satisfactory in other locations.
- Collect seed during good seed years. During poor years, seed quality may be questionable (Schubert 1974).
- Collect only mature cones. Viability of immature cones is low, and seedlings are often of poor quality.
- Collect seed from squirrel caches only as a last resort.

If a choice exists between using existing advanced reproduction or destroying it in preparation for clearcutting and planting, the following intense natural selection should be considered:

- Most dense seedling or sampling-sized trees originated after a bumper seed crop with at least 200,000 seeds falling per acre (494,208/ha).
- Out of the 200,000 seeds that fell, 15,000 to 20,000 seeds per acre (37,066 to 49,420/ha) may have germinated and produced a seedling the first year.
- Frequently 5,000 to 8,000 seedlings per acre (12,355 to 19,768/ha) survived and grew to sapling size.
- Precommercial thinning leaves 180 to 250 trees per acre (445 to 618/ha).

The genetically improved stock available now may not be superior to the naturally selected trees. Also, by using _in situ_ reproduction, we are helping to preserve our Northwest ponderosa pine gene pool (Silen 1976).

SITE PREPARATION

With the exception of a clean burn, all ponderosa pine sites need preparation before planting. This requires removing competing vegetation and obstacles that impede planting. Soil should be disturbed enough to create a good planting bed, but not endanger the site to erosion. Plantations subjected to excessive competition from brush soon after planting fail or grow so slowly that the site is eventually taken over by the competing vegetation. Use of an acceptable herbicide is often necessary, or the site will have to be prepared and replanted.

Scalping or narrow stripping is often inadequate to keep competing vegetation from taking over the site. Complete mechanical site preparation is preferred, but it may involve some environmental trade-offs. Adequate site preparation on many ponderosa pine sites is often severe, temporarily irreparable, and may destroy some land-use values for a few years. Nevertheless, it may be necessary for stand establishment.

WHEN TO PLANT

The ideal time to plant on many of our lighter soils is within 4 to 6 weeks after snowmelt in the spring. The soil is charged to field capacity after the fall rains and winter snowpack. Weather conditions from day to day during this time, however, may not always be favorable.

In the spring, areas ready to plant are frequently bare of snow before access roads are open. Plowing the roads or using snowmobiles or helicopters to reach the site before planting conditions become critical is often advisable. This is especially important on harsh, south-facing slopes.

Seedlings lifted in the nursery and planted during the period of maximum root growth capacity (January to March) have the most vigorous root growth after planting and the best chance to avoid damaging moisture stress (Cleary et al. 1978). When high elevation, late spring planting is necessary, seedlings should be lifted during maximum root-growth capacity and placed in cold storage until the site is ready in the spring.

Weather conditions at the time of planting can cause severe tree moisture stress. Weather guidelines for safe planting have been developed based on physical laws that govern seedling moisture loss (Cleary 1971).

The following weather guidelines presented by Cleary et al. (1978) are based on both physical laws and certain assumptions. Before the table guidelines are used, Cleary suggests reading the discussion (chapter 8, Cleary et al. 1978) so that you understand how these guides were generated and why certain conditions are less favorable than others.

Follow these steps to use table 6:

- Measure wind velocity with an inexpensive wind meter, air temperature, and wet bulb depression with a psychrometer. (A standard fire observation kit will work.)
- Find the point in the table corresponding to measured air temperature and wet bulb depression.
- If the point is outside the conditional zone, planting may proceed.
- If the point is inside the conditional zone, planting may proceed only when wind speed does not exceed the value appearing in the table.

Table 6--Weather guidelines for lifting and planting ponderosa pine, giving maximum allowable wind velocity for a given air temperature-wet bulb depression combination (from Cleary et al. 1978).

Air Temp. (°F)	Wet bulb depression (°F)[1]														
	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
30															20
31															19
32															19
33															18
34														19	18
35														19	17
36														19	17
37														18	16
38													20	18	16
39													19	18	16
40													19	16	15
41													19	16	14
42													18	16	13
43												20	18	15	13
44												19	17	15	13
45												19	17	15	12
46												18	16	14	12
47												18	15	13	11
48											19	17	15	12	10
49											19	16	14	12	9
50											18	16	13	11	9
51	Plant if wind velocity is less than 20 MPH.										18	15	13	10	7
52										20	17	15	12	9	7
53										19	16	13	11	9	5
54										18	16	13	10	7	6
55										18	15	12	9	7	4
56										17	14	11	8	5	3
57									19	16	13	10	7	5	2
58									19	16	13	10	7	4	1
59									18	15	12	9	5	3	
60									18	14	11	8	5	2	
61									16	13	10	7	4	1	
62								19	16	12	9	6	3	No planting—	
63								19	15	12	8	5	2	regardless of	
64								18	15	11	7	4	1	wind velocity.	
65								18	13	10	7	3			
	Plant							Conditional zone[2]							

[1]Dry bulb temperature reading minus wet bulb

[2]Planting allowed if wind velocity is less than value in table for a given air temperature-wet bulb combination.

SEEDLING CARE AND HANDLING

All preplanting precautions should be carefully followed to assure the highest possible survival of planted trees. Planting dead trees is often the result of poor care during transit and storage at or near the planting site.

During transit, trees must be protected against drying, heating, freezing, molding, and mechanical damage. Seedlings should be kept within a temperature range of 34° to 38°F (1° to 2°C) to reduce water loss and minimize metabolic activity, which can raise the temperature of seedlings in a shipping bag. Severe tissue damage can result from freezing and thawing.

Unrefrigerated trucks may be used for transporting seedlings short distances. Trees should be transported during cool but not freezing parts of the day. During warm weather, cool, wet sphagnum, or chipped ice or snow should be packed between the bundles. If the truck is not enclosed, the seedlings should be covered with canvas, with some air circulation provided between trees and the cover. Periodic checks during transit should be made even in refrigerated trucks to assure that temperatures inside the bundles are below 40°F (4°C). For long transit, a refrigerated truck is necessary.

After trees have arrived at their destination, they should be examined for evidence of heating, drying, freezing, or mold before planting or short-term storage. Trees shipped in bundles should be watered and allowed to drain. Trees shipped in bags should be sprinkled with about a pint of water and resealed promptly. If trees are to be held several days before transportation to the planting site, they should be stored at 34° to 36°F (1° to 2°C) and above 90 percent relative humidity in a room with good air circulation.

At the planting site, bagged trees should be kept refrigerated, if possible. They should never be stored in the sun or where air temperatures exceed 55°F (13°C). Solar radiation combined with air temperature can raise bag temperatures rapidly to the critical level. Bundled trees may be stored in a trench dug in the snow. At least 6 in (15 cm) of snow should be left between the ground and the trees. Bundles should be separated with packed snow, and the trench covered with snow.

NUMBER OF SEEDLINGS TO PLANT

Several important considerations--besides the first product to be harvested--must be included in the decision on how many trees to plant. Some managers have commonly planted 200 to 300 trees per acre (494 to 741/ha) with the object of having about 180 to 240 trees per acre (445 to 593/ha) with an average stand diameter of about 8- to 10-in (20- to 25-cm) d.b.h. available at the first commercial entry. Recent examination

showed too many genetically inferior trees would have to be maintained to meet the stocking goals.[4/]

The recommendation now is that 400 to 500 trees per acre (988 to 1,236/ha) be planted. Then a precommercial thinning is made after the stand is well established; trees are 8 to 10 ft (2.4 to 3.0 m) tall and dominance is clearly expressed throughout the stand. This procedure should eliminate most of the inferior trees early in the life of the stand.

PLANTING

Planting is one of the most costly investments in producing a forest. In establishing the plantation, commitments for continued protection and maintenance of the stand are made for many years. Mistakes at planting time are costly because they could conceivably be carried until the stand is finally harvested. At present, planting is the surest way to obtain ponderosa pine regeneration in the Pacific Northwest (Adams 1970). The great majority of planted lands consistently maintain adequately stocked, healthy trees. Few naturally regenerated stands do.

Natural regeneration takes place successfully in selectively cut stands, but it occurs slowly over many years. In contrast, natural regeneration under a seed tree, shelterwood, or clearcut method frequently appears successful the first several years after germination, but then seedlings succumb to birds, browsing, brush competition, frost heaving, or some other climatic action; by the time seedlings are well established, the stand is understocked. Exceptionally successful regeneration from natural seedfall does occur on higher than average sites.

Some reasons for success of planting over seeding or natural regeneration are:

- Roots are placed deep and can develop rapidly, so the tree is less likely to suffer from drought.
- Trees have a good start in competing with brush and grass.
- Well-planted, large seedlings are less likely to frost heave than the smaller, natural seedlings.
- Planted trees can survive after a moderate amount of browsing.

Plantations do occasionally fail, and the reasons can usually be traced to one of four reasons:

- Improper care of seedlings before planting.
- Poor site preparation.
- Improper planting techniques.
- Animal damage.

[4/] Study conducted by Leslie P. Yates, Deschutes National Forest.

The two most successful planting techniques have been auger planting (fig. 12) and machine planting (fig. 13).



Figure 12.--On areas that cannot be machine planted, auger planting has been successful in lighter nonrocky soils.

Auger planting has been preferred in areas where the terrain or large rocks will not permit machine planting. The auger has been the choice over the planting bar or hoe, mainly because it permits the tree to be planted in loose soil with the roots well distributed in a deep hole, with less chance of "J-rooting." On some of the pumice-mantle soils of central Oregon, the auger often penetrates the fertile, old, buried horizon. This increases chances for rapid root extension and development (Barrett and Youngberg 1970), because the auger allows mixing of the infertile C1 and C2 horizons with the moderately fertile A1, AC, and D horizons. In heavier soils, the auger loosens the soils in the planting hole and creates a much more suitable soil medium for developing a vigorous root system. Augers are more efficient in noncompacted, clean-scouring, rock-free soils such as sandy loams, sandy clay loam, and fine pumice. Augers should operate at 300 r/min or less. Faster rates will move the soil too far away from the planting hole.

If machine or auger planting cannot be used, the tile spade is often preferred. The main objections to the planting bar and hoe are that roots are often "J-rooted," and the roots are all in one plane rather than well spaced throughout the planting hole.

So far, comparative field testing of container-grown ponderosa and lodgepole pine seedlings with bare-root stock has favored the latter. Lower survival of container-grown trees was attributed to heavier animal damage than experienced by the older, woodier bare-root stock (Cleary et al. 1978).







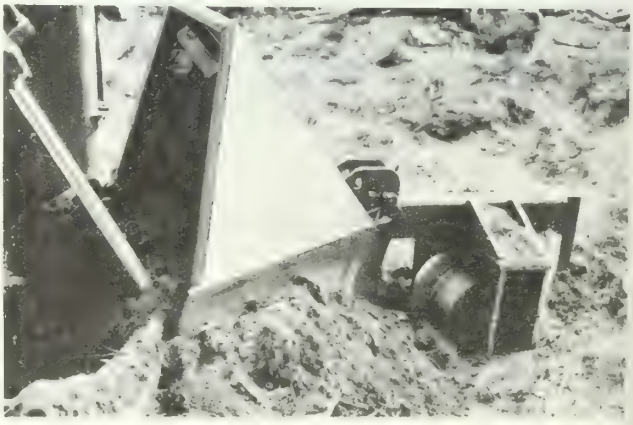


Figure 13.--The Whitfield Forest Land Semiautomatic Transplanter was used with a high degree of success in central Oregon: A, the planter operating on pumice soil; B, hydraulic system levels planter on sloping ground; C, operator feeds trees into the fingers of the semiautomatic planting mechanism; D, V-plow mounted on the C-frame removes obstacles from the planter's path, and floating coulter regulates the desired depth.

Natural Regeneration

SEEDFALL

Seed production of ponderosa pine is not regularly periodic in the Pacific Northwest. On the average, we might expect adequate crops of seed every 4 to 5 years, although some controversy exists over what constitutes an adequate crop. Dahms and Barrett (1975) reported that during the 22 years from 1953 through 1974, in only 5 years were 200,000 seeds per acre (494,200/ha) or more produced.

The question of how many seed are required to produce an acceptable crop of seedlings is not well answered. Reports vary widely outside the Pacific Northwest region. Foiles and Curtis (1973) reported that 55 seeds were needed to produce one established seedling on scarified soil. The majority of reports indicate that on the drier sites enormous amounts of seed are required for adequate regeneration. Occasionally, a year occurs in the Northwest when almost no seed is produced over a large area. Frost injury to developing conelets may be the reason (Sorensen and Miles 1974).

Seedfall usually starts in earnest late in September and continues through the winter. In one study in Oregon, Dahms and Barrett (1975) found about 38 percent of the seed from mature and immature trees had been shed by early October. By November, 82 percent of the seed had fallen, with the balance dispersed during the remaining months. Variation about the mean was great, however. For example, in the bumper year of 1958, 89 percent of the crop had fallen by October 7.

Soundness of seed was related to time of seedfall and size of crop (Dahms and Barrett 1975). Seeds shed by early October and November were 84-percent sound, and those falling between early November and the following late spring or summer were 69-percent sound.

In an old-growth stand, a significant relation was found betwen the total number of seeds produced and percent of sound seed (fig. 14). In poor seed-production years, seed was of poor quality.

Not much ponderosa pine seed disseminates beyond about 100 ft (30.5 m) from the seed source (Barrett 1966). If prevailing winds are strong enough, seed can be blown 8 chains (161 m) into a clearcutting; seed numbers at this distance, however, are only about 3 percent of those at the timber's edge. At 2 chains (40 m), seed numbers were only 22 percent of those at the timber's edge. Similar results are confirmed by workers in nearby Idaho (U.S. Department of Agriculture 1940). They found that 82 percent of ponderosa pine seed falling within 7.6 chains (153 m) of the timber's edge was confined to an area only 1.5 chains (30 m) from the source.

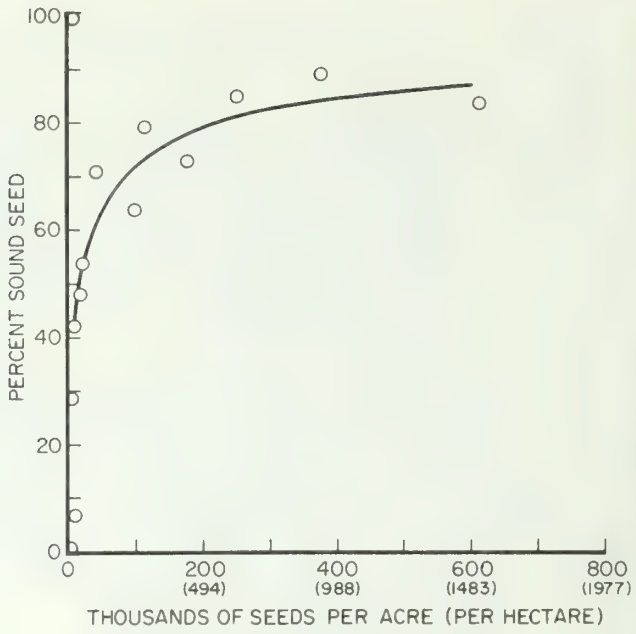


Figure 14.--Percent of seed that was sound related to crop size, old-growth ponderosa pine (adapted from Dahms and Barrett 1975).

Seed trees should be chosen with great care because they are the genetic foundation of the next crop. Dominant trees are the best choice for seed production (Fowells and Schubert 1956). Preferably, trees should have a vigor class (Keen 1943) rating of A or B. The number of old cones at the base of the tree is a good indication of the tree's ability to produce seed.

Wind firmness is an important consideration in the Northwest. This is especially critical on slopes subject to prevailing seasonal winds where shallow soils or hardpans have encouraged the development of layered root systems. Your judgment of this factor may be enhanced by examining nearby stands that have been subjected to winds for many years. Selection of the best disease-free dominants with wind firmness and good seed-production potential is the key to a good supply of seed.

NATURAL SEEDLING ESTABLISHMENT

Seedling establishment by natural regeneration in the ponderosa pine type east of the Cascade Range is highly unpredictable. This may not always be so, however. Our present knowledge will not permit us to regenerate most areas by natural seeding, especially in clearcut and shelterwood systems because of many complex, interrelated environmental factors. Often the forester has little control over these factors, which can mean success or failure in stand establishment from seed. Because our goal is a successful stand, I will discuss only factors we can partially control that will improve chances of natural regeneration.

Prolonged moisture for germination, growth, and life during the critical heat of July and August is essential. Because summers are usually dry, conservation of moisture is critical. Germination usually occurs in early spring, but rapid drying of the germinating medium often causes death of the seedling. Partial shading of seedlings affords protection from both heat and frost by reducing incoming shortwave radiation during the day and longwave radiation flux at night (Cochran 1970). A well-implemented shelterwood sometimes accomplishes this. Working the seed into the soil during logging slash piling or site preparation can often implant the seed deep enough in pumice soils so that desiccation of the root system is lessened.[5/] Although a light layer of duff and slash can act as a mulch and a radiation regulator, it can also harbor seed- and seedling-eating animals.

Existing ponderosa pine stands are present because of a series of favorable events--a good seed year preceding a mild spring, followed by an abnormally wet, cool summer. Managers interested in regenerating ponderosa pine stands by natural seed dispersal should do the following:

- Limit the undertaking to above-average sites.
- Leave a shelter of 10 to 20 trees per acre (25 to 49/ha).
- Time logging and slash disposal so that seed is mixed with the soil at least several weeks before germination.
- If necessary, apply herbicides to keep competing vegetation to a minimum until seedlings are out of danger of being overtaken by the understory vegetation.
- Seriously consider planting at least a minimum of trees to assure adequate stocking.

Intermediate Cutting

Once the pine stand is established, some type of silvicultural control over stand development is necessary to attain the intended management goal--perhaps including water, wood, forage, and wildlife--but prudent management almost always necessitates some form of tree cutting.

Natural young ponderosa pine stands established in the early 1900's often became seriously overstocked. Exceptions are the special areas where stockability is far below average (Maclean and Bolsinger 1973). On most areas, stand-density control in the management of this species is one of the foresters' most useful concepts. Without density control these forests often succumb to this sequence of events: stagnation; insect attack; tree death; understocking; and final harvest of volume well below the total potential of the land. With density control, the manager can increase the amount of usable wood produced and often enhance other resources of the forest as well.

[5/] Barrett, James W., data on file, USDA For. Serv., Silviculture Laboratory, Bend, Oregon.

A good program of intermediate harvest should have a cutting schedule that designates an appropriate stand density at intervals throughout the life of the stand. These schedules, which form the operational base for a managed forest, should be in graphs or tables, usable by both field and office personnel.

The term intermediate cutting is often misinterpreted. Here it refers to the various cuttings made during stand development from established seedling to established regeneration and final harvest. The objectives of these cuttings are improvement of the existing stand, regulation of growth, and usually provision for early financial return. No effort is directed to regeneration.

These cuttings may consist of thinnings, which are aimed primarily at controlling growth by regulating stand density. Thinnings made in young stands to regulate species composition and quality are often referred to as release cuttings and in older stands are called improvement cuttings. Sanitation salvage cuttings harvest trees that have been attacked or are likely candidates for attack by insects, disease, or both to prevent spread to other trees. Precommercial thinnings are made in stands so small that none of the felled trees are taken from the forest and used. Commercial thinnings are those where all or parts of the trees removed are used.

PRECOMMERCIAL THINNING

Precommercial thinning is usually the first cutting that takes place in a newly created stand; it is now a major undertaking on public and some private pine lands east of the Cascade Range on vast areas of natural pine regeneration. This regeneration may be as dense as 20,000 stems per acre (49,421/ha), but more commonly 3,000 to 7,000 stems per acre (7,413 to 17,297/ha), 40 to 80 years old, 2 in (5 cm) in diameter, and about 12 ft (3.7 m) tall. Other dense young stands are found with fewer trees per acre and average diameters of 4, 6, or 8 in (10, 15, or 20 cm). Stands considered unmerchantable now but that will contain a salable number of merchantable excess trees in 10 years are not usually considered for precommercial thinning.

Identifying financially attractive precommercial thinnings should be done carefully to take advantage of the potential for individual tree growth and comparative financial return. Guidelines are now available to aid in the selection of appropriate stands to thin (Sassaman et al. 1977). Vigorous, small-diameter stands on good sites are generally more attractive for thinning than a large-diameter stand on an average site. Generalizations about selections of this kind are inappropriate, however. You should consider each thinning alternative as a separate event and use the appropriate benefit-cost ratios for comparison as suggested by Sassaman.

Stands may be precommercially thinned when dominance is clearly expressed in the stand. Crowns should extend above the general crown cover with dominants receiving full light from above and partly from the sides. Codominant trees should be well represented and readily distinguishable.

Precommercial thinning of stands overtopped by mature trees is not recommended. Greatest response to thinning is obtained by complete harvest of the overstory. This does not mean that some overstory trees cannot be left for wildlife or reasons of esthetics. It does mean, however, that some loss in understory tree growth will result (Barrett 1969).

Growth response from precommercial thinning is affected by spacing, understory vegetation, site, and amount of overstory. The effect of spacing and understory vegetation on height and diameter growth is clearly shown in the Pringle Falls experiment (Barrett 1973). Here, the overstory was completely removed from an understory of saplings averaging about 2 in (5 cm) in diameter and 12 ft (3.7 m) high. Diameter and height growth increased with wider spacing (figs. 15, 16). Diameter growth appeared to reach its maximum to respond quickly, but height growth took considerably longer (fig. 17). This experiment also showed that in areas with brush species--such as bitterbrush, snowbrush, and greenleaf manzanita--the positive effects of thinning can be nullified for at least a decade by competition. This effect is most prominent at wider spacings where areas not occupied by tree roots are quickly taken over by brush. More recent results suggest that as tree crown increases, the competitive effect of these understory plants may be subdued. Other studies have shown somewhat the same effects of spacing on diameter growth (Barrett 1968, 1972, 1973; Mowat 1953), but did not show a significant effect on height growth.

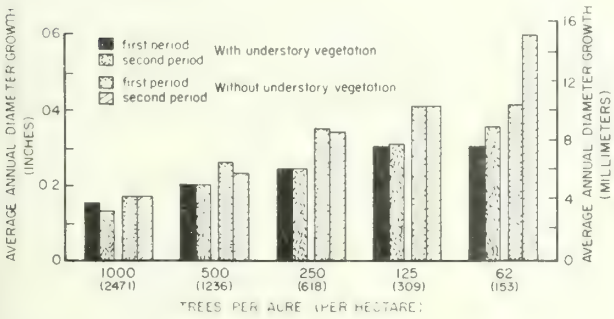


Figure 15.--Average annual diameter increment of ponderosa pine saplings during the first and second 4-year growth periods (adapted from Barrett 1970).

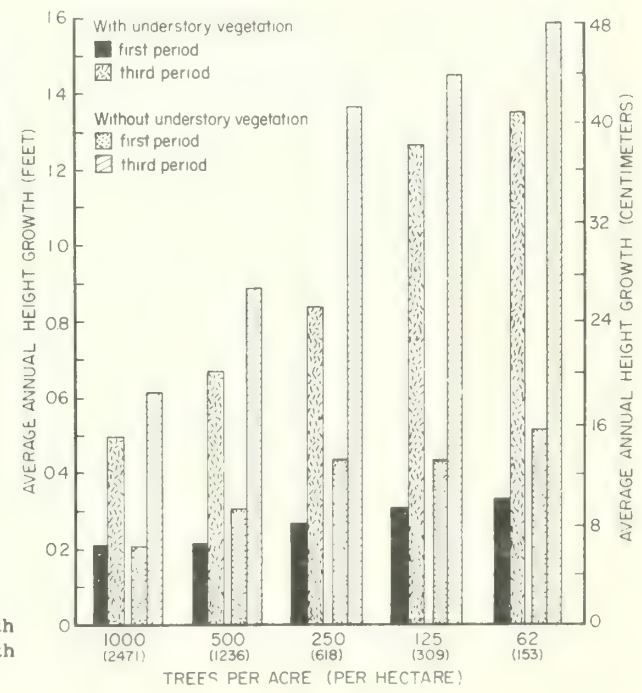


Figure 16.--Average annual height growth during the first and third 4-year growth periods (adapted from Barrett 1973).

After removal of the overstory and thinning, the annual volume increment of the sapling understory increased rapidly. During the first 4 years after thinning, 500 trees per acre (1,236/ha) produced only 12 ft^3 per acre (0.8 m^3/ha) per year in the Pringle Falls study (fig. 18). But after 12 years, the rate increased to 44 ft^3 (3.1 m^3/ha) or 3.5 times what the old, mature overstory was producing. Current annual increment is expected to peak at the 6-ft (1.8-m) spacing in about 20 years after thinning and produce about 110 ft^3 per acre (7.7 m^3/ha) per year, which may be the maximum periodic capacity of this site to produce wood fiber.

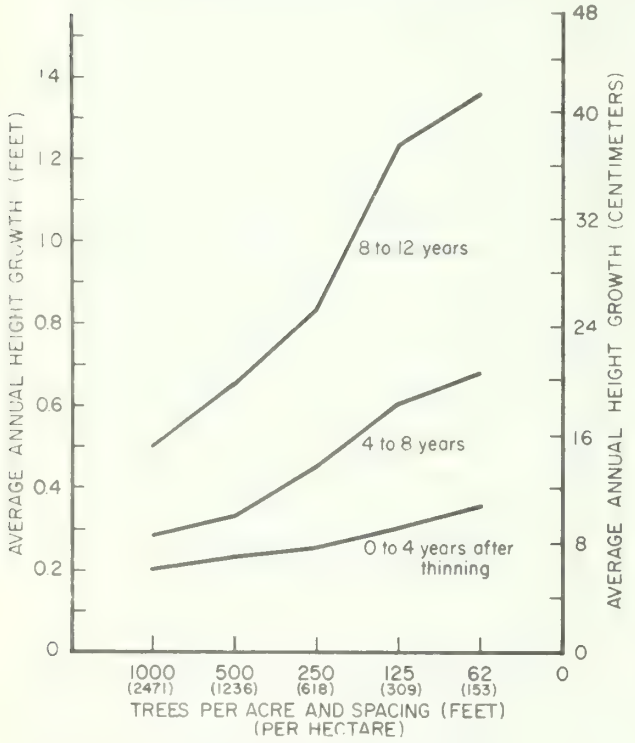


Figure 17.--Average annual height growth of released saplings during the first, second, and third 4-year growth periods in the Pringle Falls spacing study. Understory vegetation was allowed to develop naturally (adapted from Barrett 1973).

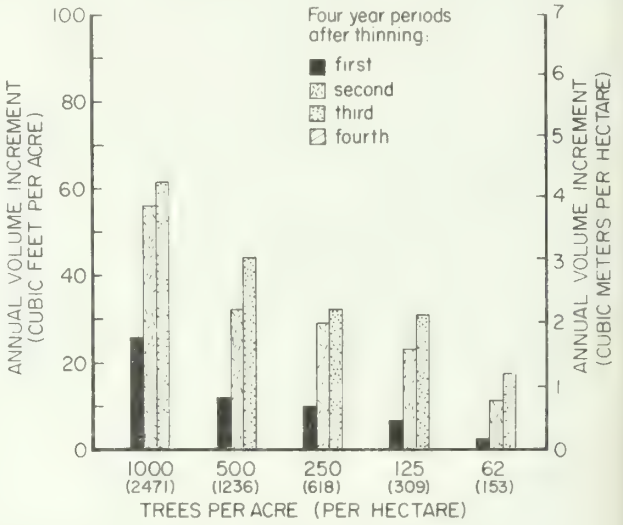


Figure 18.--Periodic annual volume increment of ponderosa pine saplings thinned to various spacings. Understory vegetation was left to develop naturally (Barrett 1973).

Average diameter of the various stands directly after thinning and 16 years later are as follows:

	Trees per acre				
	1,000	500	250	125	62
	Inches (cm)				
Vegetation left	2.0-4.0 (5.1-10.2)	1.9-4.7 (4.8-11.9)	2.1-5.7 (5.3-14.5)	2.2-7.1 (5.6-18.0)	2.2-7.7 (5.6-19.6)
Vegetation removed	1.7-4.1 (4.3-10.4)	1.8-5.1 (4.6-13.0)	1.9-6.8 (4.7-17.3)	2.5-8.5 (6.4-21.6)	2.2-10.1 (5.6-25.7)

Some individual trees at the widest spacings have reached a diameter of 12.5 in (31.8 cm) 16 years after thinning.

Present thinning recommendations for this type of stand vary with environmental constraints and management objectives. Large areas of saplings and small poles in Oregon are being thinned to 150 to 200 trees per acre (371 to 494/ha), however. Where a roundwood market is anticipated, leave-tree numbers could be increased.

Overstocked pole stands also will respond to thinning, although detectable response the first few years after thinning is almost always confined to diameter growth. Released dominant poles grew twice as fast in diameter as their unreleased counterparts in a study in central Oregon (Barrett 1963 and fig. 19). Poles were thinned to about 156 trees per acre (385/ha) and grew at the rate of 1.6 in (4.1 cm) per decade during the 6 years after thinning.

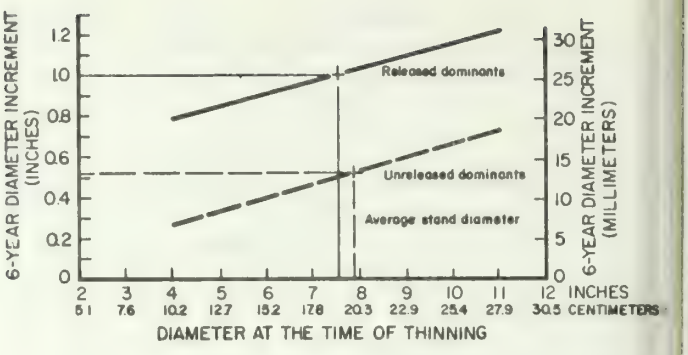


Figure 19.--Average 6-year diameter growth of dominant ponderosa pine related to initial diameter (adapted from Barrett 1963).

So far, the most satisfactory machine for precommercial thinning in this region is the conventional light chain saw with cutting bar. One worker can thin from 2 to 5 acres (0.8 to 2.0 ha) a day depending on density and size of the trees. Other machines that flail or "chew up" unwanted trees have not proved satisfactory, because tree selectivity is poor and the number of acres thinned per day is low.

Many managers think that slash from precommercial and commercial thinning represents a risk to the investment. Slash can be both harmful and beneficial, yet it is most often a hazard to the residual stand. Thinning slash is most often reduced to lessen the risk of catastrophic fire; the risk is greatest during the short period when foliage and smaller branches dry out and remain on the slash. Some owners of large private lands identify high fire-risk areas (from past fire and lightning history records) and treat only the slash on these lands, because this is more efficient and less costly than trying to treat all of it.

The "Tomahawk" (Dell and Ward 1969) is viewed as a reliable method for treating large quantities of thinning slash. This machine (fig. 20) is a slash-cutting tool mounted on the front end of a D-6 or D-7 crawler tractor. The Tomahawk cuts and crushes the slash, but the tracks of the tractor also contribute greatly to the crushing action. Although the machine has limitations, it is considered to be the most economical equipment available for meeting slash disposal objectives. A disadvantage of the Tomahawk is that slash must dry at least one season before it crushes satisfactorily, so a high risk of fire may be present during one season. When green slash is crushed by the Tomahawk, the larger stems do not touch the ground, so it is still a fire hazard when it dries. When the Tomahawk is used in dry slash that breaks readily, some ground disturbance occurs and a portion of the slash is partially worked into the soil. Some silviculturists are concerned about the possibility of nitrogen depression when slash is worked into the soil. Cochran (1968) believes this is not a problem unless the slash is chipped and actually mixed with the soil. He reported one instance where the nitrogen contributed to the soil from the foliage was about equal to the amount necessary for slash decomposition, so no net loss occurred.

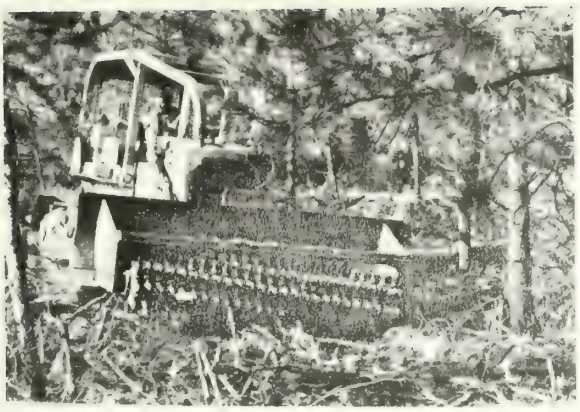


Figure 20.--The Tomahawk is probably the most useful machine found so far for treating large quantities of thinning slash.

Medium-sized crawler type tractors without the Tomahawk attachment are being used successfully to crush thinning slash. This method works well if the slash is dry and of small diameter.

In stands that average 2 to 5 in (5.1 to 12.7 cm) in diameter with leave trees widely spaced, thinning slash can be bulldozed into piles for burning. This method is especially useful where the intent is to seed the area to grass or cover for wildlife.

In pole stands that are being precommercially thinned and stands that are being commercially thinned for the first time, piling and burning can be difficult. Bucking the slash is frequently necessary so that the cut tree stems may be maneuvered between reserve trees without scarring standing tree butts.

Preliminary trials in prescribed burning of thinning slash shows considerable promise. Principles and prescriptions for using this silvicultural tool are presently being worked out.

Complete slash disposal is too expensive in most thinned stands. Exceptions may be campgrounds and heavily traveled roadside strips. Generally, managers have three goals in thinning-slash treatment: to decrease the risk of ignition; to break up the continuity of the slash; and to diminish the amount of slash.

Precommercial thinning in plantations in the Pacific Northwest is just beginning; growth results are reported for only one thinned plantation (Barrett 1972). Trees were planted at 6- x 6-ft spacing (1.8- x 1.8-m) spacing and thinned 33 years later to 8.8, 10.2, and 17.6 ft (2.7, 3.1, and 5.4 m). Response to thinning was good, even though the stand should have been thinned at a much younger age. Trees grew in diameter at the rate of 1 to 3 in (2.5 to 7.6 cm) per decade after thinning. As with other recently begun thinning trials in small poles, spacing has not yet affected height growth. The most surprising result was that although the heaviest thinning in these full-crowned trees reduced basal area 65 percent, trees in the treatment grew 80 percent of the volume produced by four times as many trees.

COMMERCIAL THINNING

The first commercial thinning in a previously unthinned ponderosa pine stand is an important undertaking in stand management, because it sets the stage for the future accumulation of wood on the best trees. Select reserve trees carefully on the basis of growth rate (present diameter and height), general health, and stem quality. Retain the best crop trees. Spacing should not be overemphasized in this thinning, because good crop trees will soon use the rooting area formerly occupied by a cut tree. One option in commercial thinning is to mark desired crop or leave trees with paint and allow the logger to remove all other merchantable material. This frequently works well for several reasons. First, the marker focuses on the best crop trees, not on the trees to be cut. Second, the logger sometimes takes the small trees, so better use is made of the forest's productivity. Third, the trees to be retained are evident to loggers, and they can protect them from damage. The tree marker can easily make a quick prism check on stocking level.

Commercial thinnings in previously unthinned stands usually remove the average stand diameter or slightly greater because an occasional large rough tree is harvested. Subsequent thinnings will be "free thinnings," where trees are removed from all crown classes.

Commercial thinnings in young stands are frequently badly needed but difficult to accomplish. Harvest trees are sometimes small and "limby". The first 16-ft (4.9-m) log usually is grade 5 (Gaines 1962). A few grade 4 logs are cut, with the remainder in grade 5. These grades saw mostly into No. 3, 4, and 5 common lumber with an average of about 55 percent of the log volume recovered as rough green lumber (Woodfin 1978). Density before thinning, in basal area, is often high. The amount of salable timber, however, may be less than 2,000 fbm per acre. To wait for later sales often endangers the stand to further beetle attack, but to sell sooner often requires a subsidy on public lands for removal of the material. About 2,000 fbm per acre is the minimum that most loggers are willing to harvest, although the amount appears to getting lower each year as pine stumpage becomes difficult to obtain. The subsidy for lesser amounts may be accomplished by including the commercial thinning in sales of larger mature timber.

Objectives of the first commercial thinning in previously unthinned stands are to reduce current mortality, to forestall future mortality by reducing density, and to provide a current stocking level that will allow optimum growth until the next stand entry.

We are not yet confident of the minimum amount of stocking that will produce maximum periodic volume increment in these stands. This information should be forthcoming soon from levels-of-growing stock studies established about 1965.

An example of density regulation in commercial thinning is shown in figure 21. The stand is on a low site containing 110 trees per acre (272/ha) with an average stand diameter of 10 in (25.4 cm) (point A). The stand can be thinned back to the recommended stocking-level curve of 65 trees per acre (161/ha), point B, or 75 trees (185/ha), if the developing course of an 8-in (20.3-cm) stand is followed.

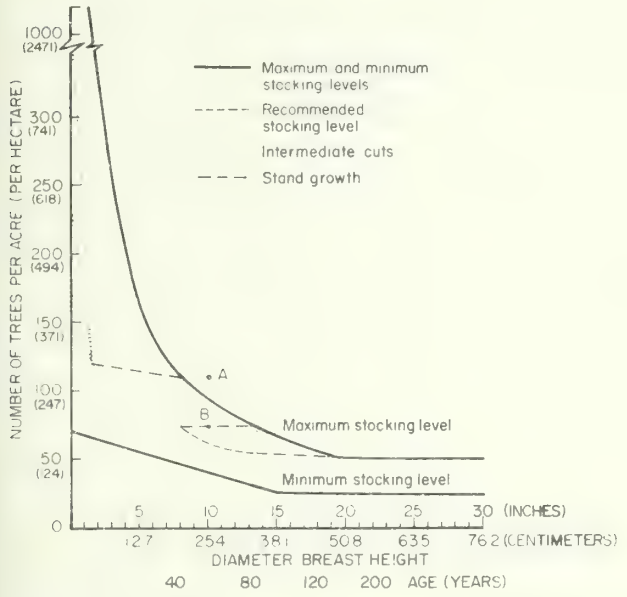


Figure 21.--Stocking-level curves for ponderosa pine where site index is V and lower (Meyer 1961), an example of precommercial thinning to 120 trees per acre (296/ha).

IMPROVEMENT CUTTING

Generally, improvement cutting is needed in stands that are close to maturity, overstocked, show evidence of annual beetle attack, or are being invaded by unwanted species. These stands are usually, but not always, in transitional zones at the higher elevations on notably productive sites. Although between 100 and 150 years old, these even-aged stands, if fully stocked, are often producing gross increments of over 100 ft^3 per acre (7 m^3/ha) per year (Barrett 1974) or more than 700 fbm per acre per year. Even at 100 years old, these stands respond to thinning by increasing in diameter growth. Basal areas are often well over 200 ft^2 per acre (46 m^2/ha), and mountain pine beetle is almost always moderately evident. Present recommendations are to thin these stands commercially from below, removing only as much basal area as necessary to reduce mortality. This preserves the productivity of the stands, while subduing the activity of mountain pine beetle (Sartwell 1971). Annual height growth at this stage in stand development is beginning to lessen, and large reductions in growing stock can drastically reduce current increment.

Some improvement cutting in combination with prescribed burning may be necessary where fir has invaded lower elevation pine stands. The fir may encourage the development of undesirable levels of tussock moth.[6/]

The elimination of incense-cedar is a never-ending process in some pine stands where it has invaded from seed of overmature trees. Early removal of these old trees is recommended.

Sanitation and salvage cutting are intermediate cuts that have been practiced since the initiation of management of our pine forests and are covered elsewhere.

Sanitation cutting, often combined with salvage cutting, harvests trees that have been attacked or are good candidates for attack by insects or disease (Sowder 1951). The object is to prevent these pests from spreading to other trees or stands. Sanitation salvage cutting is still practiced to varying degrees throughout the region and is considered essential to preserving the health and vigor of stands where a large portion of old growth is still retained.

DENSITY CONTROL

Although density control is not a method of intermediate cutting, it is discussed here because it affects the size of trees cut.

Stand-density manipulation is one of the silviculturist's most important means for influencing product size, stand-volume increment, and final yield. In addition, stand density can influence development of understory vegetation, water yield, soil stability, and habitat for wildlife and domestic stock. Therefore, any guidelines for density control must have enough flexibility to cover many alternatives for management. In the Pacific Northwest, as in most other areas in the country, merchantability standards are changing rapidly and no one really knows what will be the minimum-sized tree that can be profitably harvested in a given number of years. Also, esthetic values may put further constraints on density control.

Before any density control is implemented, a thorough stand examination is recommended. Homogeneous stands are delineated, and density, size classes, and other pertinent information are recorded. Then, density regulation may be prescribed for each stand.

[6/]Unpublished report, "A timber type evaluation of historical Douglas-fir tussock moth outbreak areas in Oregon and Washington," by Robert E. Martin and Jerry T. Williams. U.S. Dep. Agric., Douglas-fir Tussock Moth Res. and Dev. Prog. Final Rep. (on file at the For. Sci. Lab., Corvallis, Oreg.).

Presently, the National Forest System in Region 6 is using stocking-level curves to aid in precommercial and commercial thinning. These are supplemented somewhat by the "Managed Yield (MGLD)" computer program that--given predicted stand characteristics, such as tree sizes and stocking rates--calculates the expected volume, basal area, and so on for the specified ages. As described by Sassaman et al. (1977):

> The physical stocking guides used in the estimation of managed yields are commonly called stocking level curves. Basic features of stocking level curves are outlined in the Forest Service Silviculture Examination and Prescription Handbook (Region 6). By definition in the handbook, a stocking level curve is a management tool used to compare the stocking of a given timber stand in relationship to a desired (biologic) stocking level under managed conditions. Generally the curves express a desired number of trees per acre for a given diameter breast height and/or at a given age by site classes. The curves for ponderosa pine (fig. 21, 22) are based on the growth and yield tables obtained from USDA Bulletin 630 (Meyer 1961), research data from the Pacific Northwest Experiment Station, and observations of growth of stands of various densities throughout Region 6.

The guides have three curves. The upper curve shows the maximum number of healthy trees per acre for the stand's average diameter. If more trees are left, experience has shown that an unacceptable growth rate and a higher probability of insect attack and disease result. The middle curve is the recommended stocking level; it represents growing stock that will occupy the site and produce optimum wood fiber on usable stems. The bottom curve represents the lowest stocking level that will produce a harvest cut but will not produce commercial thinning volume, nor will the full site potential be used during the early part of the rotation. Stocking below this usually results in growing space occupied by unwanted trees and sometimes by undesirable understory vegetation. The curves imply that as long as the silviculturist operates between the recommended and maximum levels, the site will be fully used for production.

A demonstration of field use of the guide is shown in figure 22. In this illustration, a sapling stand is reduced from several thousand trees per acre to 180 (445/ha) point A, where average stand diameter is about 2 in (5 cm). The stand grows until it reaches an average stand diameter of 10 in (25 cm), point B, or the maximum stocking-level curve. At this point, the first commercial thinning is made, and the stand is thinned leaving 130 trees (321/ha), point C. The next entry for an intermediate cut will be made when these trees grow and reach the maximum stocking level curve and so on through point G until the final harvest is made, sometime along line H.

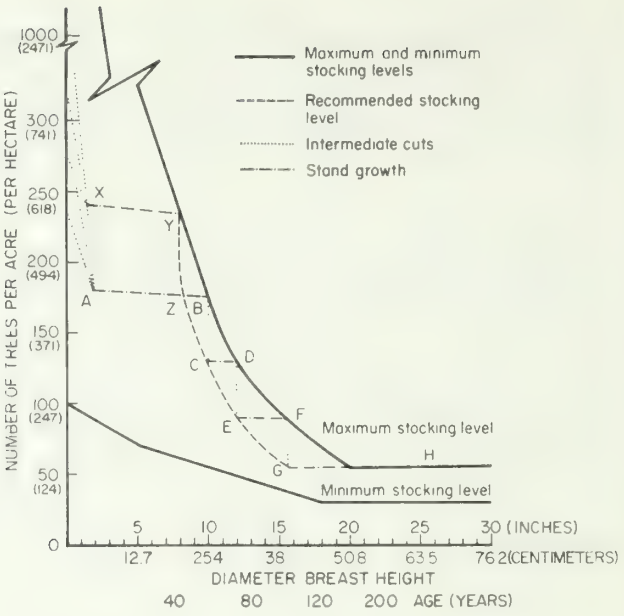


Figure 22.--Stocking-level curves for ponderosa pine where site index is IV or better (Meyer 1961). An example of precommercial thinning to 180 and 240 trees per acre (445 and 593/ha).

In an area where a roundwood market appears possible, the dense stand may be reduced by precommercial thinning to 240 trees per acre (593/ha) point X (fig. 22), with an average diameter somewhat less than 2 in (5 cm). These trees are allowed to grow until they reach the maximum curve, point Y, with an average stand diameter of 8 in (20 cm). A roundwood harvest is then made, reducing the stand to about 180 trees per acre (445/ha) point Z, shown for the sawlog regime. Theoretically, the whole curve system would move to the right as the potential of the land to produce increases. The present state of knowledge on density regulation limits us to the two curves of figures 21 and 22. More curves may come with additional data from thinning studies.

Also, useful in ponderosa pine density control is the maximum basal area concept. Visualize a maximum basal area management level on site V land (Meyer 1961) in figure 23 (Barrett 1977) of 120 ft^2 per acre (27.5 m^2/ha). This maximum is arbitrarily here because of a hypothetical potential mountain pine beetle problem (Sartwell 1971), although the stand is well beyond the maximum stocking-level curve shown in figure 21. The stand can grow to this level but should not exceed it, because of the danger of insect attack. This upper limit influences initial stand density. Suppose we thin a sapling stand to 380 trees per acre (939/ha). We can see from figure 23 that when the stand attains 120 ft^2 (27.5 m^2), average stand diameter will be slightly more than 7.5 in (19 cm). Then, a market for trees 7.5 in (19 cm) or less would be needed if thinning is from below. In contrast, a stand thinned to 200 trees per acre (494/ha) would have an average diameter slightly over 10 in (25 cm) when it reaches this upper limit of basal area where it is susceptible to insect attack. Labor conditions, depressed markets, and weather may force delays in commercial thinning stands in the future. Therefore, upper limits or "panic levels" should be set where some density regulation must occur. Strict adherence to the recommended stocking-level curve would lessen this problem.

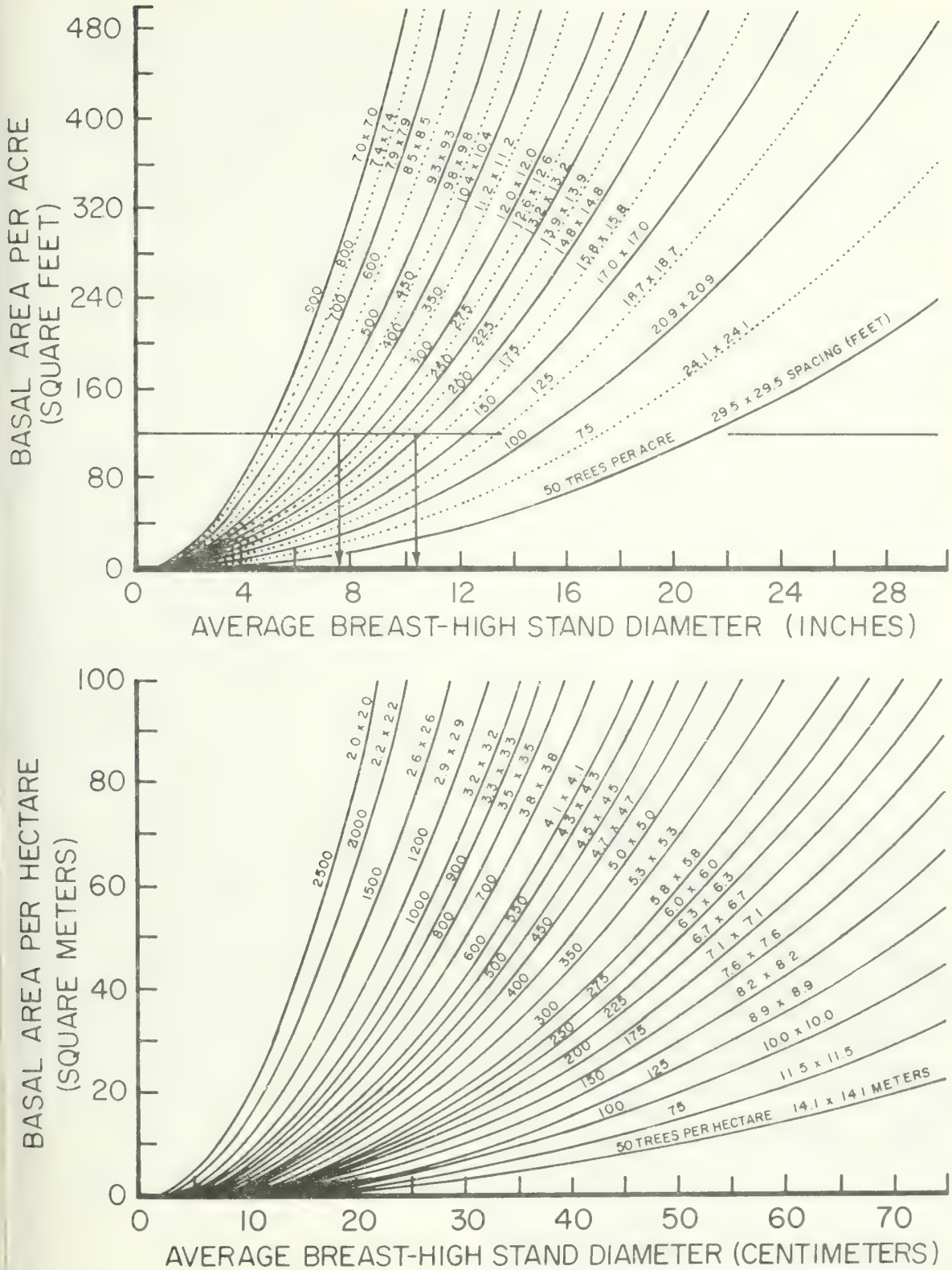


Figure 23.--Guide for stand basal area, average d.b.h., and tree spacing relations (Barrett 1977).

GROWTH AND YIELD

Juvenile Tree Development and Competition

After a natural or planted ponderosa pine seedling is established, a multitude of competitive influences can affect growth. Some of them are a necessary part of the plant community's stability, but frequently the competition may be reduced so that desired tree growth may be obtained.

Brush can be highly competitive with tree growth. Although brush has disadvantages, the beneficial effects should not be discounted. Bitterbrush and snowbrush, for example, are nitrogen fixers (Youngberg 1966). They are also probably an important link in the soil-plant-water continuum on some soils; where this is true, the competitive species should be suppressed only long enough to obtain the desired juvenile tree growth.

Sometimes brush can be a serious deterrent to development of young trees. Picture a ponderosa pine/bitterbrush-snowbrush/needlegrass community burned from lightning. The site is auger-planted with 2-0 ponderosa pine. Initial tree growth is impressive (fig. 24). Snowbrush seed, dormant in the soil for years (Gratkowski 1961) germinates and brush that survived the fire resprouts. Snowbrush grows profusely. After the third growing season, annual height growth of most of the planted trees begins to lessen. Some terminals of the more severely stressed trees have internodal lengths of only a few inches. If the brush is left untreated, brush and trees will fight for supremacy of the site for many years. Similar competitive effects are common when existing brushfields are contour-stripped and planted.



Figure 24.--Planted ponderosa pine, showing reduced height growth from brush competition. Snowbrush was treated with herbicides 1 year before picture was taken.

Just as serious, but less obvious to the casual observer, is the competitive effect of brush in recently thinned sapling stands. Both diameter and height growth of individual trees are reduced (Barrett 1973). Some form of brush control early in the rotation appears advisable where young stand growth is seriously impaired.

Grasses and other herbaceous plants can be serious competitors with natural seedlings and planted stock. This appears to be most serious when stands in fringe areas are regenerated. Often, the growth rate of grasses and sedges is faster than the seedlings, and the seedlings succumb to severe moisture stress and die.

Early tree growth can also be profoundly affected by competition with other trees. Historically, many ponderosa pine stands regenerated after abundant seedfall, on an ideal seed bed (sometimes prepared by fire); often, 5,000 to 10,000 saplings per acre (12,355 to 24,700/ha) developed. Trees often average 2 in (5 cm) in diameter, 12 ft tall (3.7 m) and 70 years old. A heavy, mature overstory frequently suppresses this reproduction. A great range in densities occurs, and each density usually exhibits different rates of height and diameter growth because of intertree competition. Size is often a poor indicator of age in these suppressed natural stands.

DIAMETER GROWTH

Ponderosa pine responds to release at almost any age if it has sufficient crown to take advantage of the additional growing space. This has become most evident in stands from 30 to 80 years old that have been suppressed for many years (fig. 25). Occasional dramatic increases in diameter growth after thinning led two workers to wonder how fast a ponderosa pine can grow under ideal conditions as a free-growing tree. Dahms and Silen[7/] visualized the free-growing tree as one extreme in the spectrum of possible spacing that could be readily identified in natural stands. After excavating roots, they concluded that roots might overlap slightly from two trees 80 ft (24.4 m) apart, but set this distance as the criterion for selecting 20 free-growing trees. Trees ranged from 5 to 20 in (13 to 51 cm) in diameter and from 19 to 36 years old. All trees averaged 4.9 in (12.4 cm) of growth during the last decade. Trees with no competitive groundcover averaged 6.5 in (16.5 cm) of growth per decade (3+ rings per inch), but those completely surrounded by understory vegetation grew only 3 in (7.6 cm) (fig. 26). The authors concluded that the potential for diameter growth had been grossly underestimated and much wider spacing should be tested.

7/Unpublished report, "An informal study of free-growing ponderosa pine trees," by Walter G. Dahms and Roy R. Silen, U.S. Dep. Agric., For. Serv. Prog. Rep., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. (on file at USDA For. Serv. Silvic. Lab., Bend, Oreg.) 1956.

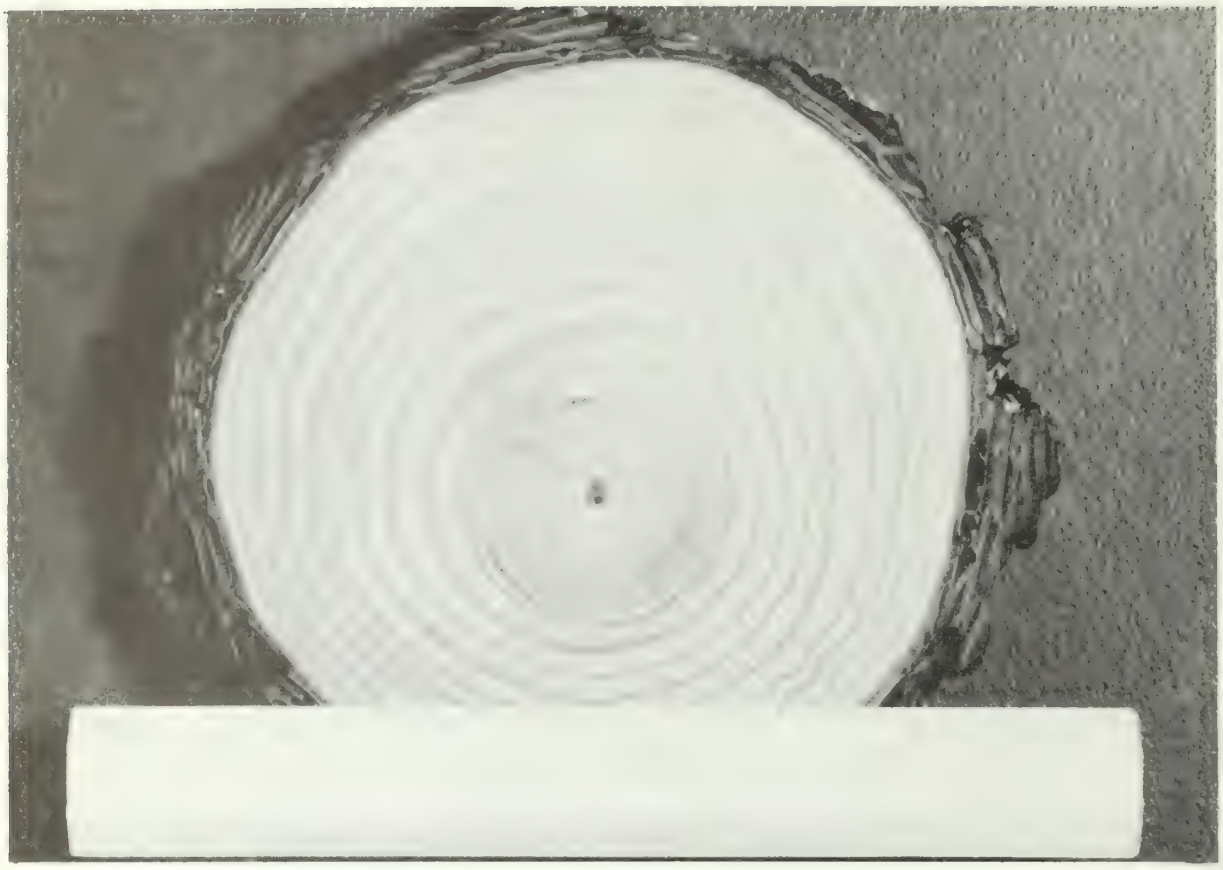


Figure 25.--Cross section from a sapling that was suppressed for over 40 years before release.

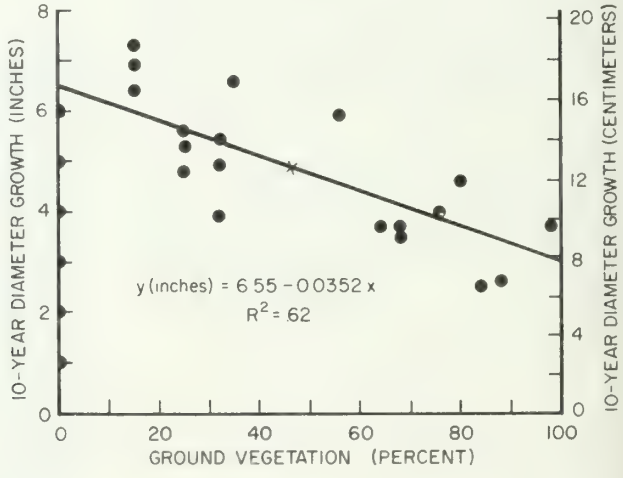


Figure 26.--Relation of 10-year diameter growth of free-growing trees to percent of ground covered by brush, grass, and other herbs (Dahms and Silen 1956).

Spacing trials before the study by Dahms and Silen consisted of modest spacings of from 6 to 9 ft (1.8 to 2.7 m). Mowat (1953) reported annual diameter increments from 0.04 to 0.16 in (1 to 4 mm) with this type of thinning.

Crop-tree thinning trials (Barrett 1969), where only trees within a few feet of the reserve tree were cut, showed only modest growth rates of 0.5 to 2.0 in (1.3 to 5.1 cm) per decade. Rates varied depending on the size of the circle of release, tree vigor, and presence or absence of overstory. Where release circles were large enough to approach an area thinning, increased growth rates were sustained. Where circles of release were small and crop trees far apart, the cleared area was quickly occupied by roots outside the circle and growth rates diminished soon after release.

More sophisticated spacing studies established in the late 1950's and early 1960's incorporated a wider range of spacings (Barrett 1968, 1970, 1972, 1973). The relation of average annual diameter growth to trees per acre for seven different studies in sapling-sized stands during the 10 years after thinning is presented in figure 27. The Pringle Falls spacing study (Barrett 1970, 1973 and figure 27--upper curve), where brushy understory vegetation was controlled, emphasizes the importance of this competition. Note how closely the diameter growth rates at the wider spacings match those of the free-growing trees (fig. 26) where ground vegetation was low. I recognize that the relations indicated in figure 27 are trends computed from only seven studies. The magnitude of the growth differences between vegetation treatments and between tree numbers may or may not apply to other areas. Understanding the general effect of tree density and understory vegetation on diameter growth, however, is important in the manipulation of second-growth stands.

A realistic assessment of stand diameter-growth would not be gained by randomly boring a few trees to compare with figure 27. Plots should be established, trees bored, and increments measured and averaged.

HEIGHT GROWTH

Height growth of immature stands of ponderosa pine in the Pacific Northwest can be influenced by site, age, stand density, overstory, brush, and shoot-boring insects. All are important considerations in evaluating stand performance and the need for silvicultural treatment.

Mowat (1950, 1953) first recognized the depressing effect of stand density and overstory presence on height growth in paired thinned and unthinned plots throughout the region. Lynch (1958) also acknowledged density as a factor in height growth when estimating site index in young, dense stands. The full significance of these observations in young, suppressed stands was not recognized until a wide range of tree spacings was observed (Barrett 1970, 1973). This study showed marked increases in height growth after thinning and overstory removal (fig. 28). In addition, height growth increased with wider spacings, although the response was not immediate. Trees

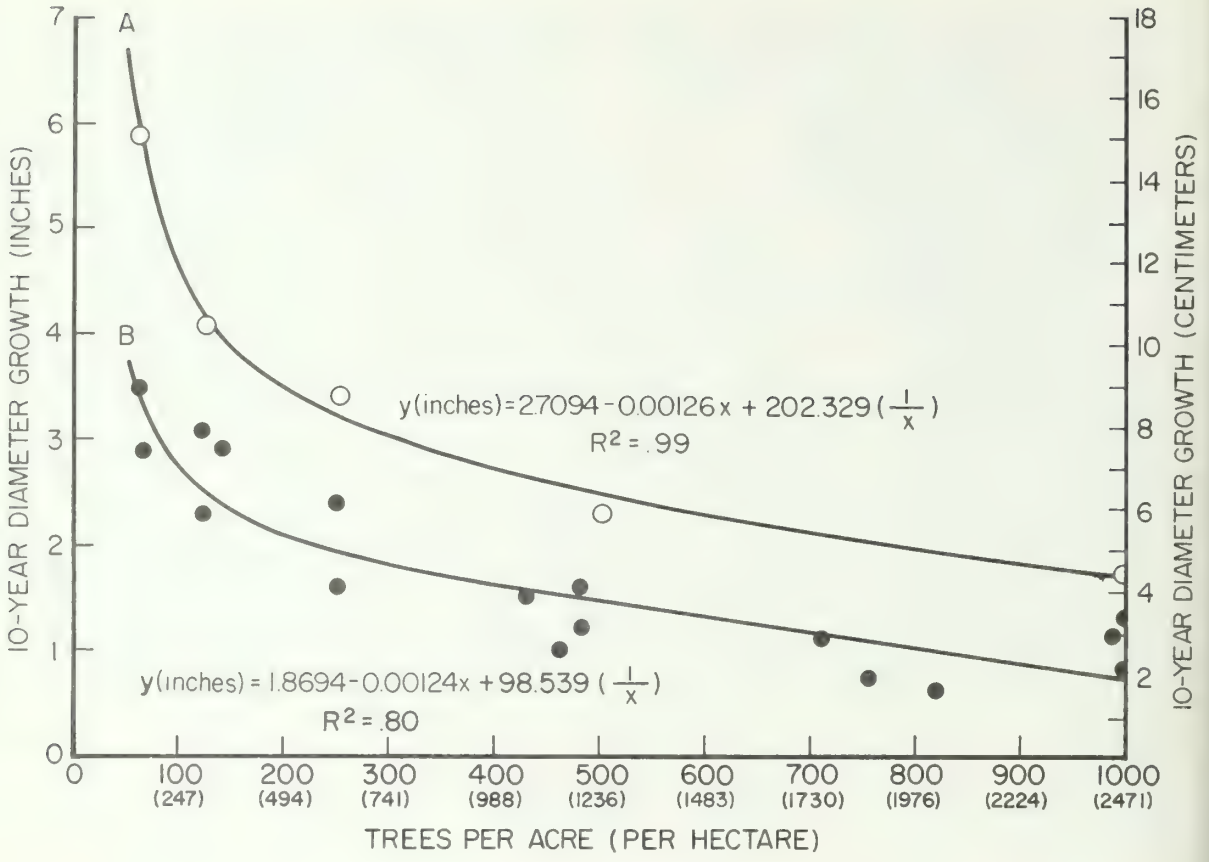


Figure 27.--Relation of 10-year diameter growth to trees per acre after thinning suppressed sapling-size ponderosa pine: A, understory vegetation controlled (Barrett 1970, 1973); and B, understory vegetation allowed to develop naturally (Mowat 1953, Barrett 1969, 1970, 1973).

did not reach their full capacity for height growth until more than a decade after thinning. Evidently, some time is needed in thinned sapling stands for roots to occupy fully the additional growing space and for tree crowns to expand, before the total capacity for height growth can be expressed.

Height-growth response in pole-sized trees is apparently delayed several years after thinning until sufficient crown buildup takes place. Barrett (1963, 1968) found no response after 5 and 6 years, but Oliver (1979)--working in northern California--found a trend of height growth related to basal area 5 to 10 years after thinning. During the period 10 to 15 years after thinning, he found height growth was clearly related to basal area. The average tree in heavily thinned plots grew more rapidly than the average tree in lightly thinned plots.

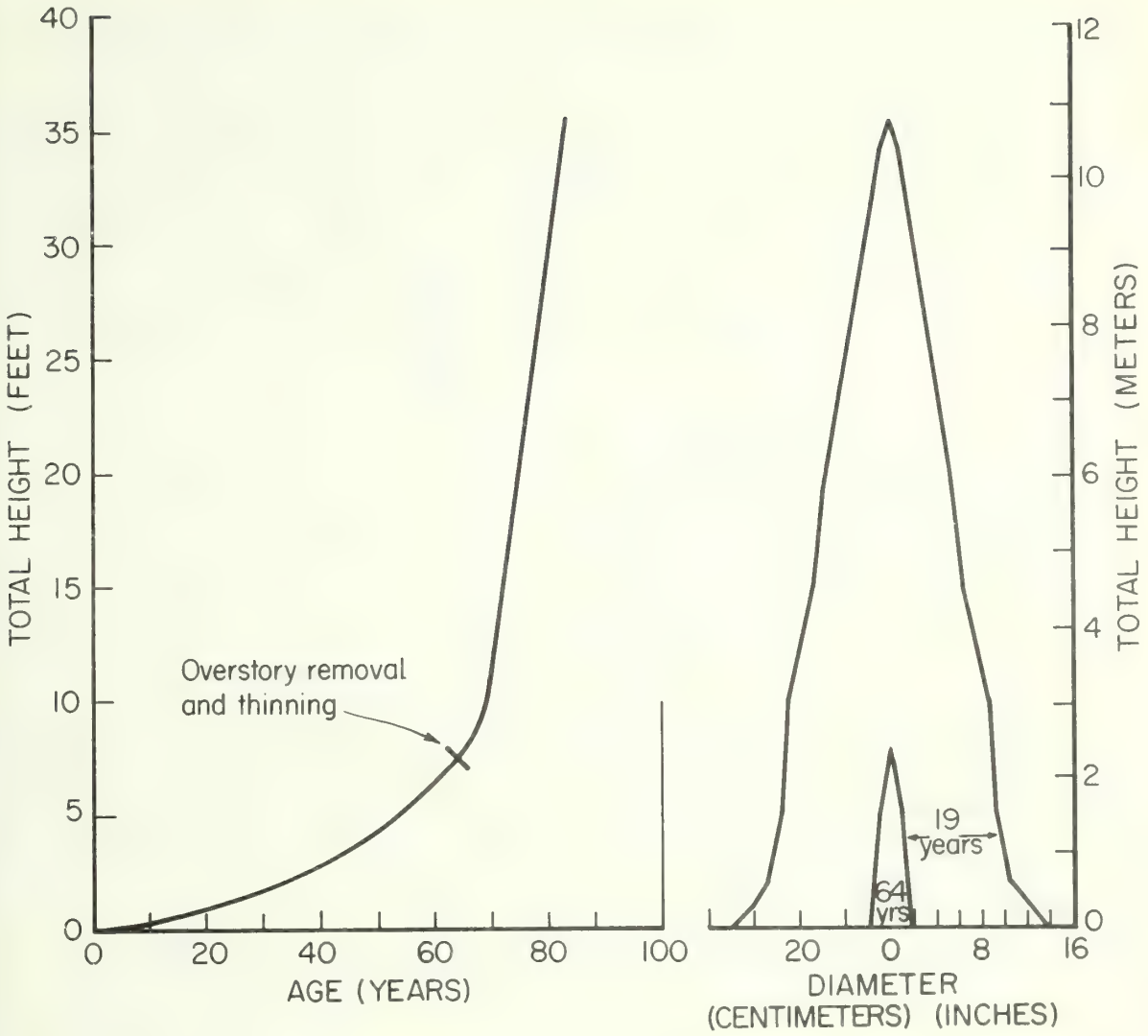


Figure 28.--Typical height-growth curve of an 83-year-old sapling released at age 64 and the stem profile before and after thinning.

As site quality increases with elevation, precipitation, exposure, and soils, annual height growth improves. Early growth, when uninhibited by stand density or overstory, is rapid and then tends to fall off with increasing age (fig. 29, Barrett 1978).

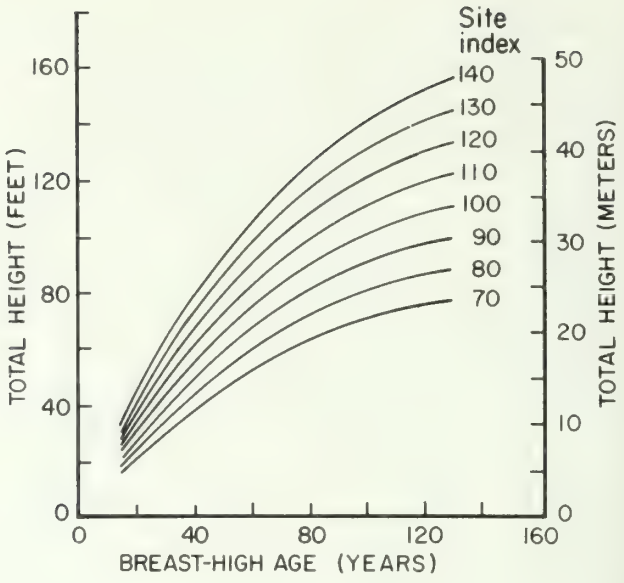


Figure 29.--Height-growth curves for managed, even-aged stands of ponderosa pine in the Pacific Northwest; heights represent the tallest trees in the stand (Barrett 1978).

VOLUME YIELD

An appreciation of the potential for volume increment in second-growth stands is necessary for making silvicultural recommendations. Most existing understory trees originated after hot fires and exceptional seed crops. With the exclusion of fire, many dense stands have stagnated and stands at lesser densities have grown at barely acceptable rates, frequently depressed by old-growth trees. If the overstory is removed from these dense stands and the stands are not thinned, they frequently reach their maximum annual increment quickly (fig. 30, line A); but the wood accumulates on trees that probably never will be merchantable because of their small size and density.

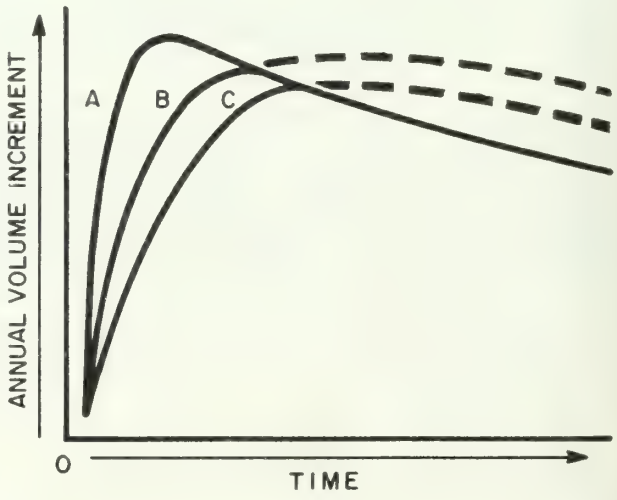


Figure 30.--Current annual increment with increasing time: A is a fully stocked natural stand; B and C represent different degrees of thinning in stand A.

Occasionally, mortality from insects or disease occurs and trees are released. Mortality occurs in patches, however, leaving large nonstocked holes in the stand. If the trees are thinned early in the life of the stand, current annual increment is not maximized as quickly, as shown in line B, in figure 30. Fewer stems simply take longer to occupy the growing space. Theoretically, the wider the spacing the longer it takes to maximize this annual production, as shown by line C, which represents a stand thinned to a wide spacing. A good example is in the periodic annual increment observed in the Pringle Falls ponderosa pine spacing study (fig. 18, Barrett 1970, 1973). Current increment is maximizing first at the narrow spacing, which may never produce a usable product; maximum production is anticipated somewhere between 80 and 110 ft^3 per acre (5.6 and 7.7 m^3/ha) per year.

These results lead to two useful ideas for managing young stands still suppressed by old growth. First, these young stands free of overstory--whether planted or thinned--have the ability to build cubic-foot production rapidly to five times or more of what the old-growth overstory was producing at the time of harvest. Second, some compromise must be made between leaving widely spaced, rapidly growing individual trees and narrowly spaced, slower growing trees that are collectively producing more wood at a slightly earlier age. This emphasizes the importance of early density regulation in ponderosa pine management.

On the other hand, evidence is accumulating that the same amount of wood fiber can be produced in about 50 years over a wide range of densities, provided the trees start from seedlings at reasonable densities and are not subjected to overstory suppression or brush competition. In one study (Barrett 1971), results suggest that, on an average site, around 160 to 180 trees per acre (395 to 445/ha) can grow as much usable wood as three to five times as many trees (fig. 31).

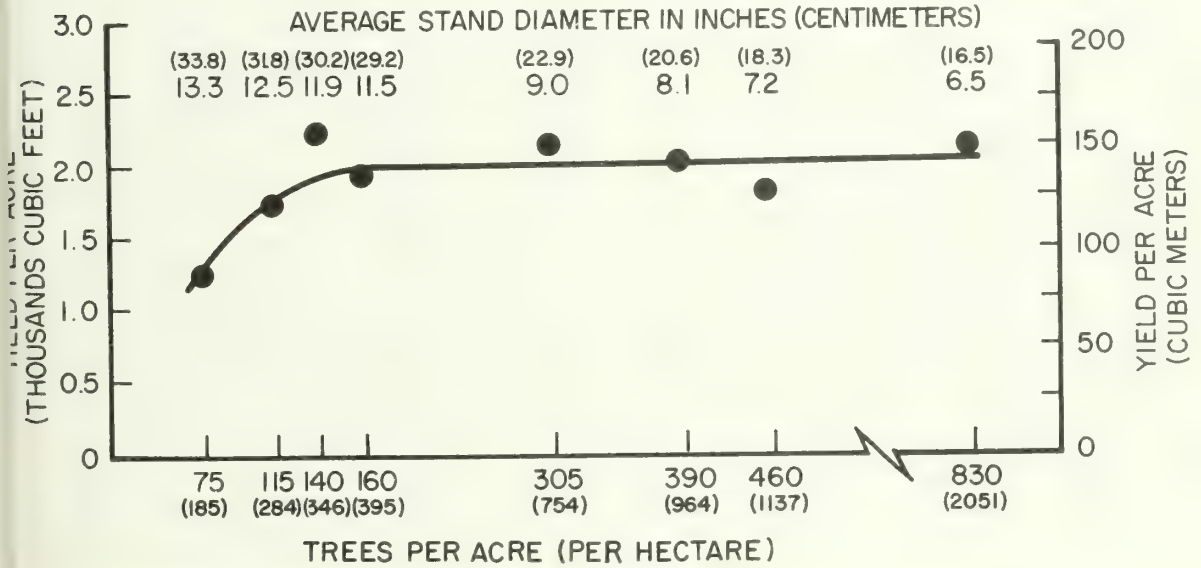


Figure 31.--Total yield and average stand diameter of site IV second-growth ponderosa pine at age 45 for various initial tree numbers per acre (Barrett 1971).

Initial densities below 160 trees per acre (395/ha) may produce a usable tree in much less time, but tree quality and area volume production may suffer. Therefore, if we plant or allow to grow 500 to 1,000 natural seedlings per acre (1,236 to 2,471/ha) till dominance is clearly expressed, then thin the stand to 160 trees or more per acre (395+/ha), and control understory vegetation early in the rotation, a major portion of the total productive capacity of the land may be captured during at least 50 years of growth.

Old, Selectively Cut Stands

DIAMETER GROWTH

Growth of older trees in selectively cut stands is affected by competition, but age and tree characteristics also play a prominent role. Keen's (1943) tree classes have long been recognized as a means of designating the growth potential of different types of trees. Briegleb (1945) described a method for using this classification in calculating volume growth of ponderosa pine forests in the Northwest.

Because Keen's system of tree classification is used so frequently in selection cutting of older stands throughout the Northwest, it is presented here in abbreviated form. Under this system, individual trees are grouped into four age classes; young, immature, mature, and overmature--designated by the numbers 1, 2, 3, and 4--and into four-crown-vigor classes; as full, good-to-fair, fair-to-poor, and very poor vigor--designated by the letters A, B, C, and D. A young tree of full vigor would be classed as 1A, a mature tree of very poor vigor a 3D. The classes are pictured in figure 32 and described fully in tables 7 and 8.

Briegleb has shown that diameter growth rate is strongly related to tree class (fig. 33).

Diameter growth rates vary within tree classes depending on tree diameter. For young vigorous trees--tree classes 1A, 1B, 2A, and 2B--diameter growth often diminishes as tree size increases. For older trees of good thrift--classes 3A, 3B, 4A, and 4B--the relation of tree size to diameter growth rate is reversed. Diameter growth rate is independent of tree size in most C-vigor classes. Trees of poor vigor--D-crown trees--in all age classes, consistently show a decline in diameter growth with increase in size. Although some large-diameter, old trees are growing slowly in diameter, remember that a yearly addition in diameter of a given thickness accumulated on a 20-in (51-cm) tree adds more volume than on a tree 10 in (25 cm) or less. Therefore, where an even flow of old-growth ponderosa pine is being maintained by selection or group selection, relative diameter growth of these trees becomes an important consideration in what will be left as growing stock during the conversion period.



Figure 32.--A ponderosa pine tree classification, based on age and vigor (Keen 1943).

Table 7--Age Classes (After Keen, by Briebleb 1945)[1/]

Character	Class 1	Class 2	Class 3	Class 4
Maturity	Young	Immature	Mature	Overmature
Age	Usually less than 80 years	Approximately 80 to 180 years	Approximately 180 to 300 years	More than 300 years
D.b.h.	Rarely over 20 inches	Rarely over 30 inches	Rarely over 40 inches	Usually large diameters in dominant trees
Height	In lower canopy usually less than 60% of total height of mature canopy	Height usually less than 90% of total height of mature canopy	Height practically that of general crown canopy (except of intermediate, suppressed, or topkilled trees)	Full height of general canopy (except suppressed, spike-topped, or broken trees)
Growth and taper	Thrifty trees making rapid height and diameter growth. Rapid taper.	Considerable height growth still in progress; good diameter growth in thrifty trees. Taper considerable.	Height growth practically complete; diameter growth slow. Moderate taper.	Making no height growth; diameter growth very slow. Least taper.
Bark color	Dark grayish brown to black (except at extreme base)	Dark reddish brown on lower half of bole; dark bark on upper half	Light reddish brown on lower three-fourths of bole; dark bark showing in upper one-fourth of bole	Light yellow; uniform color throughout bole (except at extreme top)
Bark plates	No plates. Rough bark, deeply furrowed, with narrow ridges between fissures	Narrow smooth plates between fissures	Moderately large plates between fissures	Plates usually very wide, long, and smooth; fissures often rather shallow
Branches	Branches upturned in upper three-fourths of crown; small for diameter of bole	Mostly upturned in upper half of crown; lower half horizontal or drooping; small to medium for diameter of bole	Upturned near top; middle horizontal; lower ones drooping; moderate for size of bole	Large, heavy limbs, often gnarled or crooked; mostly drooping, except in extreme top
Whorls	Whorls distinct in upper crown	Whorls distinct in upper half of crown	Whorls indistinct except at extreme top of crown	Whorls indistinct and incomplete
Top	Top usually pointed	Top usually pointed, sometimes rounded	Top usually pyramidal or rounded, sometimes pointed	Usually flat, occasionally rounded or irregular

[1/]Description primarily applicable to central and southern Oregon and northern California, Site IV.

Table 8--Crown-vigor classes (After Keen, by Briegleb 1945)[1/]

Character	Class A	Class B	Class C	Class D
Crown vigor	Full, vigorous	Good to fair	Fair to poor	Very poor
Crown length	Long, 55% or more of total height; or less only if more than average width	Average length, less than 55% of total height (approximately 30% to 55% if full and wide) or a longer crown if narrow or somewhat thin	Short (from 10% to 30% of height, if crown of normal density) or long, sparse, and narrow	Very short (less than 10% of total height) sometimes merely a tuft at top of tree, or somewhat longer when sparse and ragged
Crown width	Usually average width or wider (narrower if very long and dense)	Usually average width or narrower; may be flat on one side	Usually narrow or flat on one or more sides	Usually very narrow and sparse, or limbs all on one side
Crown density	Usually full and dense or of medium density if longer than 55%	Usually of full to medium density, not sparse or ragged	Often sparse and ragged except at very top	Sparse and ragged
Foliage	Needles of average length or longer, usually dense and thrifty	Needles of average length, usually dense and thrifty	Needles often short and thinly distributed, but of normal length and density when confined to top one-third of crown	Needles often short; foliage sparse or scattered or only partially developed, but of normal length if reduced in quantity
Position	Usually isolated or dominant, rarely codominant	Usually codominant; sometimes isolated or dominant, rarely intermediate	Usually intermediate; sometimes codominant or suppressed, but rarely isolated or dominant	Usually suppressed or intermediate, but may occupy other positions if greatly reduced in vigor.
Diameter	Large for age	Average or above for age	Usually below average for age; sometimes larger in decadent trees	Decidedly subnormal for age, but very old, decadent trees may be of large diameter

[1/] The descriptions apply to the usual types of trees found in each class; where exceptions occur, the size of living crown and amount of foliage are the primary considerations in determining the vigor class.

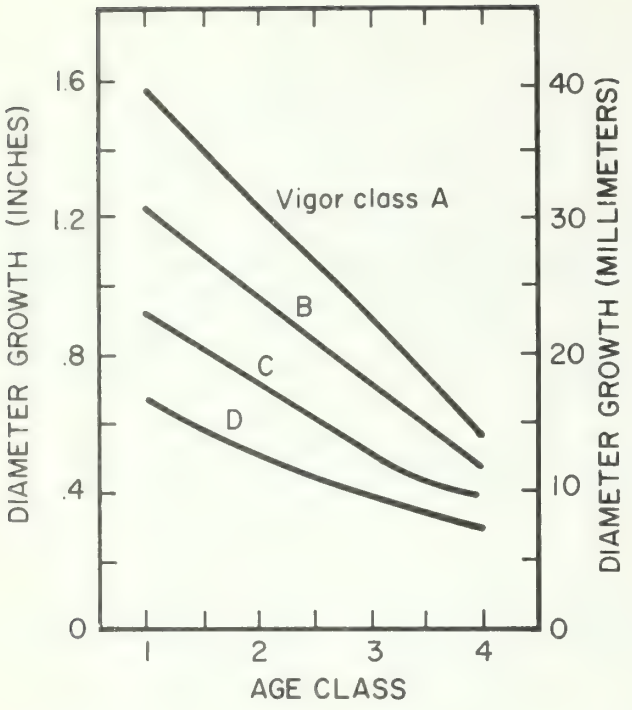


Figure 33.--Normal 10-year growth in d.b.h. by tree class (Briegleb 1945).

Some managers of selectively cut forests prefer to supplement their tree-vigor classification with an increment hammer, at least until they have confidence in their judgment of a tree's comparative growth. Keen's vigor classes are also helpful as a training aid in designating trees to be cut.

As you would expect, stand growth can be extremely variable under different methods of cutting. Mowat (1961) reports gross increments of from 28 to 220 fbm per acre per year.

Tentative Yields of Managed Stands

Yield information for managed stands based on observation of actual growth is scarce. What is available is on short periods of growth during various ages on different sites, which does, however, give some clue for periodic diameter, height, and volume increment. In addition, rough approximations of gross periodic increments and mean annual increments for natural unmanaged stands can be made using Meyer's (1961) yield table for uncut even-aged "normal" stands. These yields, if discounted for periodic thinnings, give another estimate of site productive capacity under management. From these bits and pieces of information, a first approximation of a managed-stand yield has been published for an average site (Sassaman et al. 1977). These yields (table 9) were developed for thinned stands with average leave-tree diameters of 2, 4, 6, and 8 in (5.1, 10.2, 15.2, 20.3 cm)

d.b.h. on an above-average site (site index 78, 100-year basis). A sapling stand with an average diameter of 1.5 in (3.8 cm) before thinning is thinned to 180 trees per acre (445/ha) averaging 2 in (5.1 cm) d.b.h. and 12 ft (3.7 m) high. Although the stand may actually be 50, 60, or even 80 years old, the stand is given an adjusted age of 13 years in the yield table because the tree's dimensions are similar to a natural or planted tree growing without serious competition. Similarly, the 4-in (10.2-cm) crop trees are given an adjusted age of 22 years. Stand development with commercial thinnings were calculated by the computer program "Managed Yield."[8/]

A managed-stand yield simulator based on additional growth data is now being constructed for various sites and ages and will be available from the Pacific Northwest Forest and Range Experiment Station in 1981.

STAND GROWTH

Although more and more even-aged management is being done in ponderosa pine stands of the Pacific Northwest, in a large segment of land--along highways, scenic vistas, recreation areas, and watersheds--selective cutting is an option. Another option may be an irregular shelterwood or some modification of even-aged management. Getting maximum growth in these areas, while preserving esthetic values, requires skill and care.

Structure of the reserve stand, expressed in terms of composition by Keen tree class and diameter of trees, is a major determinant of growth, often outweighing wide differences in volume of growing stock (Mowat 1961). Other stand characteristics being equal, more growth can be made by larger reserves of growing stock. In the Pacific Northwest, however, uneven-aged stands that have been lightly cut often lack younger trees of good vigor. Trying to gain increment by leaving heavier volumes often results in a loss, because the additional trees left may be of poor vigor, older, and usually larger--less efficient producers of the stand. Trees that may die before the next entry may also be included. On the other hand, trying to increase growth by removal of all mature, overmature, and low-vigor trees results in a reduction of growing stock such that the site is only partially used. Individual trees may grow fast but are not able to compensate for the low volume per acre. The growing stock reserve that will maximize volume increment obviously lies somewhere between these extremes.

[8/]Developed by U.S. Forest Service, Division of Timber Management, Region 6, Portland, Oregon.

Table 9--Yield per acre of ponderosa pine precommercially thinned to leave-tree diameters of 2, 4, 6, and 8 inches on land with an average site index of 78 (adapted from Sassaman et al. 1977). Metric equivalents are given in table 9a.

Stand characteristics									Intermediate harvests				
Stand age	Trees	Average diameter at breast height[1/]	Average height	Basal area	Merchantable volume to a 6-inch top	Scribner volume to a 6-inch top	Total volume[2/]	Mean annual increment[3/]	Trees	Average diameter at breast height[1/]	Basal area	Merchantable volume to a 6-inch top	Scribner volume to a 6-inch top
Years	Number	Inches	Feet	Square feet	Cubic feet	Board feet	Board feet	Cubic feet	Number	Inches	Square feet	Cubic feet	Board feet
						LEAVE-TREE DIAMETER 2 INCHES							
13	900+	1.5	12	12	--	--	--	--	--	--	--	--	--
37	175	10.0	38	95	1,130	3,913	3,913	31	48	11.0	32	402	1,471
60	124	13.0	56	114	2,253	9,715	11,185	44	41	13.0	38	745	3,212
80	81	16.1	68	114	2,735	13,112	17,794	48	24	16.0	34	800	3,822
100	56	18.8	78	108	2,888	15,031	23,536	48	--	--	--	--	--
120	56	21.3	86	139	4,019	22,046	30,551	50	--	--	--	--	--
140	56	23.4	94	167	5,095	28,837	37,342	50	--	--	--	--	--
160	54	24.9	100	183	5,850	33,870	42,375	49	--	--	--	--	--
180	53	25.9	106	194	6,511	38,555	47,060	47	--	--	--	--	--
200	52	26.7	110	202	6,999	41,918	50,423	45	--	--	--	--	--
220	51	27.4	113	209	7,390	44,586	53,092	42	--	--	--	--	--
						LEAVE-TREE DIAMETER 4 INCHES							
22	900+	2.9	23	44	--	--	--	--	--	--	--	--	--
43	175	10.0	42	95	1,202	4,247	4,247	28	48	11.0	32	430	1,586
60	124	12.2	55	101	1,924	7,963	9,549	39	41	12.0	32	612	2,504
80	81	15.3	67	103	2,427	11,275	15,365	43	24	15.0	30	689	3,177
100	56	18.1	77	100	2,644	13,604	20,870	44	--	--	--	--	--
120	56	20.4	85	127	3,645	19,666	26,933	45	--	--	--	--	--
140	56	22.5	93	155	4,664	26,129	33,396	46	--	--	--	--	--
160	54	24.0	99	170	5,385	30,780	38,046	44	--	--	--	--	--
180	53	25.0	105	181	6,014	35,258	42,525	43	--	--	--	--	--
200	52	25.8	109	189	6,480	38,495	45,762	41	--	--	--	--	--
220	51	26.5	112	195	6,857	41,077	48,344	39	--	--	--	--	--
50	175	10.0	46	95	1,452	5,526	5,526	29	50	11.0	33.0	533	2,070
70	122	12.2	64	99	2,131	9,215	11,286	38	40	12.0	31.4	511	2,000

50	175	10.0	46	95	1,452	5,526	5,526	29	50	11.0	33.0	533	2,070
70	122	12.2	64	99	2,131	9,215	11,286	38	40	12.0	31.4	671	2,883
90	80	15.1	74	100	2,496	11,947	16,900	41	23	15.0	23.2	707	3,375
120	56	18.6	82	106	2,930	15,217	23,545	40	--	--	--	--	--
140	56	19.9	90	121	3,616	19,634	27,962	40	--	--	--	--	--
160	56	22.4	96	153	4,736	26,572	34,899	40	--	--	--	--	--
180	54	23.4	102	161	5,234	29,959	38,236	40	--	--	--	--	--
200	53	24.2	106	169	5,671	33,039	41,367	38	--	--	--	--	--
220	52	25.4	109	183	6,277	37,162	45,489	33	--	--	--	--	--
						LEAVE-TREE DIAMETER 8 INCHES							
45	900+	5.3	40	153	1,930	--	--	43	--	--	--	--	--
60	175	10.0	48	95	1,479	5,610	5,610	25	48	11.0	32	523	2,017
80	124	12.4	62	104	2,205	9,577	11,594	34	40	12.0	31	658	2,814
100	82	15.0	72	101	2,474	11,706	16,537	37	23	15.0	28	694	3,284
120	58	17.5	80	97	2,623	13,401	21,515	37	--	--	--	--	--
140	58	19.6	88	122	3,567	19,179	27,294	39	--	--	--	--	--
160	58	21.2	94	142	4,411	24,554	32,668	39	--	--	--	--	--
180	56	22.3	100	152	4,843	27,178	35,293	37	--	--	--	--	--
200	55	23.1	106	160	5,351	30,801	38,916	36	--	--	--	--	--
220	54	23.9	110	168	5,800	33,893	42,008	35	--	--	--	--	--

1/Average diameter of all trees.

2/Scribner volume to a 6-inch top.

3/Merchantable volume to a 6-inch top.

Table 9a--Yield per hectare of ponderosa pine precommercially thinned to leave-tree diameters of 5.1, 10.2, 15.2, and 20.3 centimeters on land with an average site index of 78

Stand characteristics							Intermediate harvests			
Stand age	Trees	Average diameter at breast height[1/]	Average height	Basal area	Merchantable volume to a 15.2-cm top	Mean annual increment[2/]	Trees	Average diameter at breast height[1/]	Basal area	Merchantable volume to a 15.2-cm top
Years	Number	Centimeters	Meters	Square meters	Cubic meters	Cubic meters	Number	Centimeters	Square meters	Cubic meters
				LEAVE-TREE DIAMETER 5.1 CENTIMETERS						
13	2,224+	3.8	3.7	2.8	--	--	--	--	--	--
37	432	25.4	11.6	21.8	79	2.2	119	27.9	7.3	28
60	306	33.0	17.1	26.2	158	3.1	101	33.0	8.7	52
80	200	40.9	20.7	26.2	191	3.4	59	40.6	7.8	56
100	138	47.8	23.8	24.8	202	3.4	--	--	--	--
120	138	54.1	26.2	31.9	281	3.5	--	--	--	--
140	138	59.4	28.7	38.8	357	3.5	--	--	--	--
160	133	63.2	30.5	42.0	409	3.4	--	--	--	--
180	131	65.8	32.3	44.5	456	3.3	--	--	--	--
200	128	67.8	33.5	46.4	490	3.1	--	--	--	--
220	126	69.6	34.4	48.0	517	2.9	--	--	--	--
				LEAVE-TREE DIAMETER 10.2 CENTIMETERS						
22	2,224+	7.4	7.0	10.1	--	--	--	--	--	--
43	432	25.4	12.8	21.8	84	2.0	119	27.9	7.3	30
60	306	31.0	16.8	23.2	135	2.7	101	30.5	7.3	43
80	200	38.9	20.4	23.6	170	3.0	59	38.1	6.9	48
100	138	46.0	23.5	23.0	185	3.1	--	--	--	--
120	138	51.8	25.9	29.2	255	3.2	--	--	--	--
140	138	57.2	28.3	35.6	326	3.2	--	--	--	--
160	133	61.0	30.2	39.0	377	3.1	--	--	--	--
180	131	63.5	32.0	41.6	421	3.0	--	--	--	--
200	128	65.5	33.2	43.4	453	2.9	--	--	--	--
220	126	67.3	34.1	44.8	480	2.7	--	--	--	--
				LEAVE-TREE DIAMETER 15.2 CENTIMETERS						

LEAVE-TREE DIAMETER 15.2 CENTIMETERS

32	2,224+	10.7	9.4	21.4	--	--	--	--	--	--
50	432	25.4	14.0	21.8	102	2.0	124	27.9	7.6	37
70	301	31.0	19.5	22.7	149	2.7	99	30.5	7.2	47
90	198	38.4	22.6	23.0	175	2.9	57	38.1	5.3	49
120	138	47.2	25.0	24.3	205	2.8	--	--	--	--
140	138	50.5	27.4	27.8	253	2.8	--	--	--	--
160	138	56.9	29.3	35.1	331	2.8	--	--	--	--
180	133	59.4	31.1	37.0	366	2.8	--	--	--	--
200	131	61.5	32.3	38.8	397	2.7	--	--	--	--
220	128	64.5	33.2	42.0	439	2.3	--	--	--	--

LEAVE-TREE DIAMETER 20.3 CENTIMETERS

45	2,224+	13.5	12.2	35.1	135	3.0	--	--	--	--
60	432	25.4	14.6	21.8	103	1.8	119	27.9	7.3	37
80	306	31.5	18.9	23.9	154	2.4	99	30.5	7.1	46
100	203	38.1	21.9	23.2	173	2.6	57	38.1	6.4	49
120	143	44.5	24.4	22.3	184	2.6	--	--	--	--
140	143	49.8	26.8	28.0	250	2.7	--	--	--	--
160	143	53.8	28.7	32.6	309	2.7	--	--	--	--
180	138	56.6	30.5	34.9	339	2.6	--	--	--	--
200	136	58.7	32.3	36.7	374	2.5	--	--	--	--
220	132	60.7	33.5	38.6	406	2.4	--	--	--	--

1/Average diameter of all trees.

2/Merchantable volume to a 15.2-centimeter top.

FERTILIZING STANDS

Previous discussions in this paper have shown that diameter and sometimes height growth can be increased in young stands by thinning and brush control. The increased growth rate probably results from additional soil moisture and nutrients available to leave trees. This has led some researchers to speculate that fertilization might increase wood production in the drier portions of the region.

The work of Youngberg (1975) and Agee and Biswell (1970) suggests that fertilizing unthinned dense stands of ponderosa pine is not a reasonable practice. Dense stands tend to stagnate, and some of the increased growth is added to trees that will never reach usable size. If fertilizer is added to thinned stands, only the growth rate of trees that will be harvested as usable wood will benefit. Youngberg (1968) applied 200 lb nitrogen (N) per acre (224 kg/ha) to a dense, small pole stand of ponderosa pine and to an adjacent stand thinned to 12- x 12-ft (3.7- x 3.7-m) spacing. Five years after treatment, increases in basal area were:

	Percent
Unfertilized, unthinned	19
Fertilized, unthinned	25
Unfertilized, thinned	35
Fertilized, thinned	50

Since then, Cochran (1973, 1977, 1978) has installed experiments in central and eastern Oregon that have expanded our knowledge of fertilizer response. He found that N in the form of urea produced the most response. In central Oregon, recent results suggest that when N is combined with sulfur (S) it becomes an even greater growth stimulant. An experiment in central Oregon (Cochran 1978) on typic Cryandept (Shanahan series) soil, developing on Mazama pumice showed that a thinned stand with an initial basal area of 90 ft^2 per acre (20 m^2/ha) and producing 60 ft^3 (4.2 m^3/ha) per acre per year may be increased to 80 ft^3 (5.6 m^3/ha) by the addition of 200 lb (224 kg/ha) of elemental N per acre (fig. 34). A suggested benefit from the addition of 30 lb (34 kg/ha) S per acre was a new fertilizer, sulphated urea 40-0-0-6--applied at 500 lb (561 kg/ha) per acre--would approximately duplicate what Cochran tried.

Response to fertilization in other parts of the region is questionable. Cochran (1978) believes, however, that N at 200 lb per acre (224 kg/ha) (urea at 435 lb per acre (488 kg/ha)) will increase growth of many pine stands on nonpumice soils east of the Cascades in Oregon and Washington. Response is now known to last at least 4 years in some areas and as long as 8 years in others.

Cochran (1975) also reported large increases in grass production by the addition of fertilizers in thinned stands of lodgepole pine in the pumice zone.

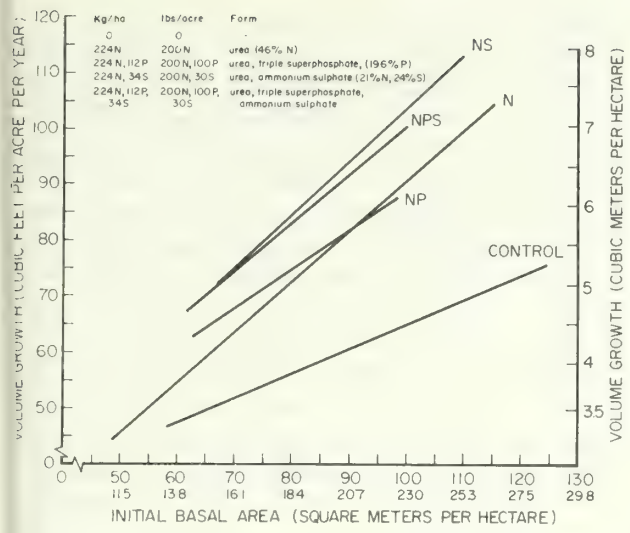


Figure 34.--Individual regressions for volume growth in response to fertilization with nitrogen (N), phosphorus (P), and sulfur (S) as a function of initial basal area (Cochran 1978).

Fertilizer trials with planted stock on pumice soils have been disappointing. Placing fertilizer in the planting hole has not produced the desired increase in height growth (Barrett and Youngberg 1970). The best of the fertilizers tested produced only an average 10-in (2.5-cm) height growth advantage in 7 years. The object of these trials was to find a growth-promoting substance that would stimulate height growth so that the seedling would be better able to compete with understory vegetation, be unattractive to browsing animals, and survive under adverse weather. Many times the desired height growth has been shown to be attainable by elimination of competing vegetation through adequate site preparation.

USE OF HERBICIDES

Need

Frequently we need to control vegetation that is competing with trees in onderosa pine stands in the Pacific Northwest, almost always early in the otation--when the site is being prepared for planting or when established oung trees must be released from competing vegetation.

Many acres of ponderosa pine forest land east of the Cascade Range are ccupied by native shrubs, mostly evergreen. In southwestern Oregon, com- eting evergreen and deciduous brush and tree species abound. Trees may be bsent because seedlings are unable to compete with the brush; if trees re present, they are unable to grow at acceptable rates because of competi- ion for light and soil moisture. Brush frequently overtops young trees for any years in forest openings, and wood production ceases for decades. Where rees overtop the brush and make acceptable height growth, brush is not con- idered a problem. Indeed, some brush species may contribute nutrients or therwise benefit the site (Youngberg 1966). Grasses and sedges can also ompete with pine seedlings on drier sites.

Some of the most troublesome brush species in eastern Oregon and Washington are greenleaf manzanita, snowbrush, golden chinkapin, Sierra chinkapin, and antelope bitterbrush. Manzanita is the most light-demanding species and is found in large and small openings in the forest canopy. Snowbrush often occurs with manzanita in openings but is more shade tolerant and can be found growing well beneath adequately stocked pine stands. Chinkapin is found on north slopes at higher elevations on moist sites. It has a high tolerance for shade and can be found thriving under heavy overstories. Bitterbrush grows abundantly, from semiarid conditions to transitional zones at the higher elevations where it is replaced by snowbrush, low-growing shrubs, or both.

Greenleaf manzanita, snowbrush, and chinkapin are all evergreen. Bitterbrush is deciduous. Snowbrush and chinkapin sprout after death or cutting of the aerial parts, but greenleaf manzanita does not. Response of bitterbrush to various cultural practices is not clear; plants have been observed to sprout after prescribed burning, damage by logging, and occasionally after spraying.

Application

Over the past several decades, much public attention has been drawn to the use of herbicides in our forests. During this time, we have learned much about using these chemicals safely and effectively. Gratkowski (1975) states:

> Although use of herbicides is complicated, research and experience during the past 20 years have shown that only a few herbicides are useful in Pacific Northwest silviculture. With modest effort, foresters can readily learn to consider the factors involved, prescribe treatments, and use these few herbicides safely and effectively.
>
> Safety and economy demand that herbicidal chemicals be used as sparingly and infrequently as possible to accomplish our silvicultural objectives. Effective use requires that we apply minimal amounts of herbicides at the proper time of the year to obtain the maximum degree of control on undesirable species without damaging desirable tree species, wildlife browse, or esthetically desirable shrub species.

Herbicides are used to release conifers from competing vegetation by increasing the amount of light reaching the pine seedling and decreasing competition for soil moisture. All the vegetation need not be killed; we only need a high degree of defoliation, a fair amount of top-kill, and as little resprouting as possible.

Phenoxy herbicides, especially 2,4-D and 2,4,5-T, are now the most useful herbicides in silviculture. As release sprays, these herbicides are most effective when applied at 1 to 3 lb acid equivalent per acre (1.1 to 3.4 kg/ha) (Gratkowski 1975). These chemicals are used on 75 percent of the acreage treated annually. Atrazine, picloram, silvex, and amitrol-T are also used frequently. Successful application is a combination of correct dosage, timing (season), and the best selective chemical.

EFFECTIVENESS OF HERBICIDES ON BRUSH

Dahms (1961) reported foliage sprays of 2,4-D and 2,4,5-T to be highly and equally effective on manzanita from early May to early July. One-half pound per acre (1.1 kg/ha) in an emulsion carrier or 0.75 lb (0.8 kg) in a water carrier gave 80-percent brush kills. He found that as the season progressed from summer into fall, brush became less and less susceptible to these herbicides. His tests during the fall, however, were not extensive; further research is needed.

The most effective chemical to control snowbrush in central Oregon is 2,4,5-T, but Dahms (1961) found that snowbrush sprouted vigorously after all chemical treatments. Rates of 1 lb/acre (1.1 kg/ha) in an emulsion and 1.5 lb (1.7 kg/ha) in water produced good kills. Gratkowski (1975) found late summer sprays of 2,4,5-T in water carriers safely released ponderosa pines from snowbrush competition in southwestern Oregon.

Bitterbrush has been killed without resprouting in experimental plots using 1 lb per acre (1.1 kg/ha) 2,4,5-T in water and diesel oil. In one area in central Oregon, 2 lb per acre(2.2 kg/ha) of 2,4,5-T in water were applied to a plantation just before pine and bitterbrush bud burst to suppress manzanita and snowbrush without killing the bitterbrush. Unseasonably warm weather followed the spraying and a 90-percent kill of the snowbrush and manzanita resulted without detectable effect on bitterbrush. This trial, which was never repeated, needs to be explored further.

Dahms (1961) found that 2,4,5-T was the most effective chemical on chinkapin, and an emulsion was better than a water carrier. Mid-June treatments produced a better kill of aerial parts than treatment in late September, but fall treatment may delay sprouting. Gratkowski (1975), working in southwestern Oregon, found chinkapin resprouted abundantly after initial treatment of mature plants; repeated treatments are needed to get a high kill.

EFFECT OF HERBICIDES ON PONDEROSA PINE

Dahms (1961) found that ponderosa pine in central Oregon can tolerate about twice as much 2,4,5-T as 2,4-D and about twice as much of either chemical in water as in an emulsion. Recent studies by Gratkowski (1978), however, showed no practical difference in damage from 2,4-D and 2,4,5-T on small pines during the autumn-spring period in the Cascade Range. This relation needs to be tested in the drier portions of eastern Oregon and Washington. Dahms (1961) found tolerance of pine also varied with season. Trees were most damaged by early July treatments and least damaged in late September. This is also true in southwestern Oregon (Gratkowski 1961, 1977). Gratkowski (1978) found ponderosa pine susceptible to damage from foliage sprays of 2,4-D and 2,4,5-T before height growth began in the spring. He found trees most susceptible during active growth in May and June. He concluded that late summer treatment is best for minimum damage to ponderosa pine.

The importance of season of application should be emphasized. Dahms (1961) found in central Oregon that, as the season progressed into fall, ponderosa pine was less damaged by spray application but some brush species became more difficult to kill. On the other hand, Gratkowski (1975) found that late summer was the only period when ponderosa pines can be safely released from brush competition with phenoxy herbicides in southwestern Oregon. Successful release spraying has been achieved in central Oregon from mid-May to mid-June with slight damage to the pine, but on some areas sprayed during this season, extensive damage to the pine was observed. Gratkowski (1977) believes we can eliminate this damage with late summer sprays of 2,4,5-T in a water carrier. He cautioned, however, that unusual August rain can result in late summer leader growth or induce physiological changes that make pines susceptible to damage from late August or early September herbicidal sprays.

Late summer spraying also has some distinct operational advantages east of the Cascade Range. Elevation influences the initiation of brush and tree growth in the spring. In the spring, lower elevation brush fields may be ready to spray but slightly higher fields are still partially covered with snow. This frequently results in spray-timing problems and necessitates recalling aerial spray equipment, adding to the cost of applying the herbicide. Late summer spraying could eliminate this problem. Again, let me emphasize that Dahms' (1961) work suggested that brush species east of the Cascade Range are much less susceptible to spray as summer progresses into fall. Therefore, further spray testing in eastern Oregon and Washington is needed during the late summer to determine if adequate brush kills can be obtained.

GRASS CONTROL

Atrazine is one of the most useful herbicides for grass control in the Pacific Northwest (Gratkowski 1975). Crouch and Hafenstein (1977) found it very effective on herbaceous vegetation in south central Oregon when applied by helicopter at 4 lb of active ingredient per acre (4.5 kg/ha) in the fall. Application before autumn rains begin is recommended, because the formulation must be leached into the soil where it can be absorbed through the root systems of susceptible grass species.

Dalapon is also effective in controlling grass competing with pine seedlings. Usually it should be applied at least 2 weeks before planting.

Gratkowski (1975) did not recommend atrazine-dalapon mixtures on ponderosa pine after observing extensive defoliation of pines.

Trials by Dimock (1977a) of a combination of 8 lb per acre (9 kg/ha) dalapon and 4 lb (4.5 kg/ha) atrazine as a broadcast spray shortly after planting gave excellent grass and forb control without damaging the pine. Control persisted through the second growing season. Dimock (1977b) also reported good results with Velpar R and Roundup.

Regulations

Federal and State regulations now require that only herbicides labeled nd registered for forest use be applied on forest lands. Questions on egistration of a particular formulation should be directed to the appro- riate State Department of Agriculture, the Oregon State Board of Forestry, he Washington State Department of Natural Resources, or the Environmental rotection Agency, which is now responsible for federal registration of all esticides. Federal foresters applying herbicides on forest land must con- ult their regional pesticide coordinator to secure approval for treatment.

FIRE

History and Ecology

Fire scars on old-growth trees present good evidence that repeated low- ntensity fires burned over most of the ponderosa pine type. These ground ires consumed branches, fallen trees, understory vegetation, and some young rees. The fires burned from 6 (Soeriaatmadja 1966) to 47 years (Weaver 959, 1961) apart, with most occurring somewhere between the two extremes Martin and Johnson 1979). Low-intensity fires kept many of the pine for- sts open and parklike and also served to maintain ponderosa pine in areas here the more tolerant climax tree species would have attained dominance. he reason for this is that saplings or larger-sized ponderosa pine are much ore fire resistant than many of the true firs and Douglas-fir. Fire- ontrol activities, initiated about 1900, have resulted in a replacement of onderosa pine with white fir, grand fir, incense-cedar, and Douglas-fir.

Succession has been influenced by the presence or absence of fire. ifferent species of brush react differently to fire. Bitterbrush, for xample, may be completely killed by a hot ground fire but survive low- ntensity fires. Brush species such as manzanita and snowbrush may in- rease after fire because it aids in germination of their seeds (Gratkowski 961). Periodic ground fires may advance, back up, or merely hold succes- ion at a given stage (Martin et al. 1976). A moderately hot fire, for xample, may thin an overly dense stand and move it forward in succession o a mature ponderosa pine-bitterbrush community. Exclusion of fire has requently altered vegetation to an unfavorable condition and has promoted he buildup of fuels so that wild fires can become catastrophic.

Through careful, prescribed burning today, managers can duplicate some f the more favorable natural fires of the past to accomplish specific bjectives on a definite area.

Fire Effects

Fire effects depend on the fuels and weather conditions. By careful prescription and application of fire, the forest manager can modify fire intensity and fuel consumption, which affect what the fire will do to plants, water, atmosphere, soil, and nutrients.

Plants, especially trees, have varying degrees of resistance to fire. Ponderosa pine is probably the most resistant of western trees throughout its life (Martin and Dell 1978) and thus has a distinct advantage for survival in a prescribed burn of mixed conifers. Western larch is next, because of its thick bark and ability to grow new leaves after scorching. Old larch trees are considered more resistant to fire than pine. Large Douglas-fir is resistant because of its thick bark, but the crowns are sensitive to scorching. Lodgepole pine is much less resistant. Fire kills hemlock, true firs, and spruce much more readily than other trees.

The ability of grasses, shrubs, and short trees to maintain themselves through periodic burning depends upon their sprouting and seed characteristics. Martin and Dell (1978) present a useful summary table on effects of fire on 25 plant species.

Wildfires and intensely hot slash fires over large areas can affect water by increasing turbidity, changing chemical content, and influencing flooding and low water levels. Prescribed burning can be conducted to make these negative effects minimal or even to improve water quality and quantity (Ingebo and Hibbert 1974). Watershed experts should be included in prescription writing if water quality is a concern.

The greatest public concern in a prescribed burn is smoke. Atmospheric stability and wind direction must be considered to avoid problems in smoke-sensitive areas.

Fuels in prescribed fires contain nutrients vital to the plants you want to grow. Most of the nutrients will remain in place unless the fire becomes too hot or heavy precipitation follows the burn. Soils may actually become water repellent in areas where heavy fuel concentrations are consumed.

In view of these effects of fire on plants, water, atmosphere, and soil nutrients, fires that accomplish the objective but are still of low intensity are essential.

Prescribed-Fire Options in Ponderosa Pine Stands

Use of prescribed fire on lands east of the Cascades in the Pacific Northwest is relatively new, but research, interest, and use as a silvicultural tool are progressing rapidly. The expanding research project at the U.S. Forest Service Silviculture Laboratory in Bend, Oregon, on the use of prescribed fire will supply many of the answers needed for full-scale operation within the next 5 years.

Even though prescribed burning has just started in this region, some use may be made of it already. One of the "safest" options we have open to us now is where old-growth overstory has been harvested, the understory saplings thinned, and the thinning and logging slash piled and burned. Several years after thinning, tree seedlings and brush respond to additional light and soil moisture and begin to compete with crop trees (Barrett 1973). Light burning, as soon as fuel accumulation is heavy enough to carry the fire, would allow the remaining crop trees to develop their maximum capacity for diameter and height growth. Subsequent fires at 10- to 15-year intervals would kill unwanted reproduction and brush.

Another option showing promise and needing further work is burning under thinned stands where trees have been left that are lightly to moderately infected with dwarf mistletoe. Most infections are concentrated in the lower branches and fire will scorch these branches, thus reducing infections per tree.

Brush fields with a few scattered sawlog-sized trees may be burned successfully although the treatment prescription may call for an herbicide or desiccating chemical in combination with fire.

Light thinning slash that is partially green may be burned safely without crop-tree damage if residual trees are at least 10 to 12 ft (3 to 3.7 m) tall. Very low intensity burns will leave trees 6 to 8 ft (1.8 to 2.4 m) tall unharmed (Wright 1978). When stands reach 30 ft (9 m), thinning slash of around 30 tons per acre (67.2+/ha) has been reduced by burning.[9/]

We can now maintain clean understories in merchantable ponderosa pine stands that have a litter and grass understory. We do not yet have the answers to burning heavy accumulations of windfalls, tops, litter, and shrubs, or using fires to thin dense stands of ponderosa pine safely (Wright 1978). Fire prescription for a wide variety of purposes needs to be documented. Fire effects on herbs and shrubs need to be carefully recorded--not only immediate effects, but species shifts with time and recovery periods for desirable species. Only through careful documentation and record-keeping will the usefulness of prescribed burning become available to the practicing forester.

Planning a Prescribed Burn

Planning a prescribed burn in the inland Northwest has been described in great detail by Martin and Dell (1978), who recommend the following preparation for a prescribed burning operation:

[9/]Martin, R. E. 1978. Principles and prescriptions for burning ponderosa pine thinning slash. Paper presented at AAAS-SAF Meeting, Seattle, June 1978. Being prepared for publication.

1. Reconnaissance of the area, including inspection and classification of the plant community.

2. Determination of specific objectives and how these objectives fit into management goals for the land unit as a whole.

3. Analysis of budgeting, costs, manpower, equipment, and other logistical needs that must be considered in planning and accomplishing the burn.

4. Thorough review of the planned burning and discussion with other disciplines to identify potential current and future influences and impacts of the burn on all resources.

5. Scheduling of time required to accomplish planned burning for the optimum time of year, including coordination needed with other units, agencies, etc.

6. Determination of specific prescription elements (fuel, weather, and ignition) needed to accomplish objectives.

7. Preparation of a written plan that provides a place for summary documentation of all factors.

CONSIDERATIONS FOR THE FUTURE

A large portion of silvicultural and management research in ponderosa pine forests has concentrated on regeneration, growth, stand development, and final harvest. Our knowledge has expanded tremendously in these areas. Little, however, has been done to show how different silvicultural systems contribute to or detract from various multiple-use objectives. Much documented information exists on such things as forage production under different degrees of canopy cover, thermal cover for big game, nesting habits of birds, watershed yields, and brush development under various stand density regimes--among others. Some information is available on favorable or unfavorable responses of various habitat types to certain silvicultural systems. This knowledge needs to be brought together into one publication for land managers so they may estimate the full impact of tradeoffs where one resource may be emphasized over another.

Throughout the West is a glaring lack of replicated silvicultural systems trials in various major habitats of the ponderosa pine type. These could be benchmark studies that would serve pine managers for many future rotations. Many disciplines--such as management of watersheds, range, wildlife, timber, landscape, logging, fuels, and prescribed burning--could be included in the undertaking. In addition to providing new information, studies of this kind will help to validate present-day predictions in a multitude of disciplines. Also, they would provide excellent ground for communicating with the public on management of renewable resources.

The conversion by fire control of 25 percent of the commercial forest land east of the Cascades to mixed conifer or some single species is an alarming prospect to some insect ecologists. Drastic changes in the forest brought about by human activity are potentially dangerous. Such a conversion needs to be critically examined so we do not create breeding habitat for an undesirable insect.

The yield tables for managed stands of ponderosa pine, to be generated in a year or two, will be based on limited data and will need updating as growth information becomes available. Even though a change in research emphasis occurs, these spacing and levels-of-growing-stock studies, established in the 1950's, can continue to improve our yield estimates. They should be periodically measured, maintained, and reported for several decades.

As is often true, abundant knowledge creates the need for more. Ponderosa pine stands in the Pacific Northwest grow under such varied conditions that solving silvicultural problems in this region is a never-ending process that will continue to challenge the ingenuity of foresters.

LITERATURE CITED

Adams, Ronald S.
1970. Ponderosa pine regeneration problems in the West Coast states. In Regeneration of ponderosa pine. R. K. Hermann, ed. p. 12-18. Symp. Proc. Sept. 11-12, 1969, Oreg. State Univ. Sch. For. Pap. 681, Corvallis.

Agee, James K., and Harold H. Biswell.
1970. Some effects of thinning and fertilization on ponderosa pine and understory vegetation. J. For. 68(1):709-711, illus.

American Ornithologist's Union.
1957. Check-list of North American birds. 5th ed. 691 p. Port City Press Inc., Baltimore, Md.

Anthony, Richard M., Victor G. Barnes, and James Evans.
1978. "Vexar" plastic netting to reduce pocket gopher depredation of conifer seedlings. In Proc. Eighth Vertebrate Pest Conf., p. 138-144. Univ. Calif., Davis.

Arkelton, Elvera A.
1967. Ponderosa pine bibliography through 1965. USDA For. Serv. Res. Pap. INT-40, 150 p., Intermt. For. and Range Exp. Stn., Odgen, Utah.

Arkelton, Elvera A.
1974. Ponderosa pine bibliography II. 1966-1970. USDA For. Serv. Gen. Tech. Rep. INT-12, 63 p., Intermt. For. and Range Exp. Stn., Ogden, Utah.

Baldwin, Ewart M.
1964. Geology of Oregon. 2d ed. 165 p., illus. Univ. Oreg. Coop. Bookstore, Eugene.

Barnes, V. G., Jr.
1973. Pocket gophers and reforestation in the Pacific Northwest: A problem analysis. Spec. Sci. Rep. Wildl. No. 155, 18 p. U.S. Fish and Wildl. Serv., Washington, D.C.

Barnes, Victor G., Jr.
1974. Response of pocket gopher populations to silvicultural practices in central Oregon. In Wildlife and forest management in the Pacific Northwest, p. 167-175. Hugh C. Black, ed. For. Res. Lab. Sch. For., Oreg. State Univ., Corvallis.

Barrett, James W.
1963. Dominant ponderosa pines do respond to thinning. USDA For. Serv. Res. Note PNW-9, 8 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1966. A record of ponderosa pine seed flight. USDA For. Serv. Res. Note PNW-38, 5 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1968. Response of ponderosa pine pole stands to thinning. USDA For. Serv. Res. Note PNW-77, 11 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1969. Crop-tree thinning of ponderosa pine in the Pacific Northwest. USDA For. Serv. Res. Note PNW-100, 13 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1970. Ponderosa pine saplings respond to control of spacing and understory vegetation. USDA For. Serv. Res. Pap. PNW-106, 16 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1971. Ponderosa pine growth and stand management. In Precommercial thinning of coastal and intermountain forests in the Pacific Northwest, p. 5-9, illus. Wash. State Univ., Pullman.

Barrett, James W.
1972. Large-crowned planted ponderosa pine respond well to thinning. USDA For. Serv. Res. Note PNW-179, 12 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1973. Latest results from the Pringle Falls ponderosa pine spacing study. USDA For. Serv. Res. Note PNW-209, 22 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1974. High yields from 100-year-old ponderosa pine. USDA For. Serv. Res. Note PNW-220, 12 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1977. A field guide for stand basal area, average diameter, and tree spacing relationships. USDA For. Serv. Res. Note PNW-298, 4 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1978. Height growth and site index curves for managed, even-aged stands of ponderosa pine in the Pacific Northwest. USDA For. Serv. Res. Pap. PNW-232, 14 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W., and C. T. Youngberg.
1970. Fertilizing planted ponderosa pine on pumice soils. In Regeneration of ponderosa pine, p. 82-88, R. K. Hermann, ed. Symp. Proc. Sept. 11-12, 1969, Oreg. State Univ. Sch. For. Pap. 681.

Barrett, James W., Stanley S. Tornbom, and Robert W. Sassaman.
1976. Logging to save ponderosa pine regeneration: A case study. USDA For. Serv. Res. Note PNW-273, 13 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Bassett, Patricia M.
1977. Timber resources of southwestern Oregon. USDA For. Serv. Res. Bull. PNW-72, 29 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Briegleb, Phillip A.
1945. Calculating the growth of ponderosa pine forests. USDA For. Serv. Prog. Rep., 60 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Campbell, D. L., and J. Evans.
1975. "Vexar" seedling protectors to reduce wildlife damage to Douglas-fir. U.S. Fish and Wildl. Serv. Leafl. 508, 11 p. Washington, D.C.

Capp, J. C.
1976. Increasing pocket gopher problems in reforestation. In Proc. Seventh Vertebrate Pest Conf., p. 221-228. Univ. Calif., Davis.

Childs, T. W.
1968a. Elytroderma disease of ponderosa pine in the Pacific Northwest. USDA For. Serv. Res. Pap. PNW-69, 45 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Childs, T. W.
1968b. Comandra rust damage to ponderosa pine in Oregon and Washington. USDA For. Serv. 8 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Christensen, M. D., J. A. Young, and R. A. Evans.
1974. Control of annual grasses and revegetation in the ponderosa pine woodlands. J. Range Manage. 27(2):143-145.

Cleary, B. D.
1971. Weather guidelines to improve initial survival of planted seedlings. 9 p., illus. Weyerhaeuser Co., Centralia, Wash.

Cleary, Brian D., Robert D. Greaves, and Richard K. Hermann.
1978. Regenerating Oregon's forests. 286 p. Oreg. State Univ. Ext. Serv., Corvallis.

Cochran, P. H.
1968. Can thinning slash cause a nitrogen deficiency in pumice soils of central Oregon? USDA For. Serv. Res. Note PNW-82, 11 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H.
1970. Seeding ponderosa pine. In Regeneration of ponderosa pine, p. 28-35, R. K. Hermann, ed. Symp. Proc. Sept. 11-12, 1969, Oreg. State Univ. Sch. For. Pap. 681. Corvallis.

Cochran, P. H.
1973. Response of individual ponderosa pine trees to fertilization. USDA For. Serv. Res. Note PNW-206, 15 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H.
1975. Response of pole-size lodgepole pine to fertilization. USDA For. Serv. Res. Note PNW-247, 10 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H.
1977. Response of ponderosa pine 8 years after fertilization. USDA For. Serv. Res. Note PNW-301, 7 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H.
1978. Response of pole-size ponderosa pine stand to nitrogen, phosphorus and sulphur. USDA For. Serv. Res. Note PNW-319, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H., and Carl M. Berntsen.
1973. Tolerance of lodgepole and ponderosa pine to low night temperatures. For. Sci. 19(4):272-280, illus.

Crouch, Glenn L.
1976. Deer and reforestation in the Pacific Northwest. In Proc. Seventh Vertebrate Pest Conf., p. 298-301, Charles C. Siebe, ed. March 9-11, 1976, Univ. Calif., Davis.

Crouch, Glenn L., and Erwin Hafenstein.
1977. Atrazine promotes ponderosa pine regeneration. USDA For. Serv. Res. Note PNW-309, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Dahms, Walter G.
1961. Chemical control of brush in ponderosa pine forests of central Oregon. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Pap. 39, 17 p. Portland, Oreg.

Dahms, Walter G., and James W. Barrett.
1975. Seed production of central Oregon ponderosa and lodgepole pines. USDA For. Serv. Res. Pap. PNW-191, 13 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Daubenmire, R., and Jean B. Daubenmire.
1968. Forest vegetation of eastern Washington and northern Idaho. Wash. State Univ. Agric. Exp. Stn. Tech. Bull. 60, 104 p., illus. Pullman.

Dealy, J. Edward.
1971. Habitat characteristics of the Silver Lake mule deer range. USDA For. Serv. Res. Pap. PNW-125, 99 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Dell, John D., and Franklin R. Ward.
1969. Reducing fire hazard in ponderosa pine thinning slash by mechanical crushing. USDA For. Serv. Res. Pap. PSW-57, 9 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Dimock, E. J. II.
1977a. Enhancing survival of conifers with herbicides on dry sites. West. Soc. Weed Sci. Proc. 30:74-75.

Dimock, E. J. II.
1977b. Enhancing survival of planted conifers with herbicides on grassy sites. West. For. and Conserv Assoc., "What's new in reforestation" Proc. (In press.)

Dolph, Robert E.
1971. Oregon pine Ips infestation from red slash to green trees--a misconception. In Precommercial thinning of coastal and intermountain forests in the Pacific Northwest, p. 53-62, illus., David M. Baumgartner, ed. Symp. Proc. Feb 3 and 4, 1971, Coop. Ext. Serv. and Dep. For. and Range Manage., Wash. State Univ., Pullman.

Dyrness, Christian Theodore.
1960. Soil-vegetation relationships within the ponderosa pine type in the central Oregon pumice region. Ph.D. thesis, Oreg. State Univ., Corvallis. 217 p.

Foiles, Marvin W., and James D. Curtis.
1973. Regeneration of ponderosa pine in the northern Rocky Mountain-Intermountain Region. USDA For. Serv. Res. Pap. INT-145, 44 p., illus. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Fowells, H. A., and G. H. Schubert.
1956. Seed crops of forest trees in the pine region of California. U.S. Dep. Agric. Tech. Bull. 1150, 48 p., illus.

Franklin, Jerry F., and C. T. Dyrness.
1973. Natural vegetation of Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-8, 417 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Furniss, R. L., and V. M. Carolin.
1977. Western forest insects. USDA For. Serv. Misc. Publ. No. 1339, 654 p., illus.

Gaines, Edward M.
1962. Improved system for grading ponderosa pine and sugar pine logs in trees. USDA For. Serv. Tech. Pap. 75, 21 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Garrison, G. A., and J. M. Skovlin.
1976. Plant names and symbols for ecosystems inventory and analysis. USDA For. Serv. Gen. Tech. Rep. PNW-46, 263 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Gratkowski, H.
1961. Brush seedlings after controlled burning of brushlands in southwestern Oregon. J. For. 59(12):885-888, illus.

Gratkowski, H.
1975. Silvicultural use of herbicides in the Pacific Northwest forests. USDA For. Serv. Gen. Tech. Rep. PNW-37, 44 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Gratkowski, H. J.
1977. Seasonal effects of phenoxy herbicides on ponderosa pine and associated brush species. For. Sci. 23(1):2-12, illus.

Gratkowski, H. J.
1978. Annual variation in effect of 2,4-D and 2,4,5-T on ponderosa pine. For. Sci. 24(2):281-287, illus.

Hall, Frederick C.
1973. Plant communities of the Blue Mountains in eastern Oregon and southeastern Washington. USDA For. Serv. R-6 Area Guide 3-1, 62 p. Pac. Northwest Region 6, Portland, Oreg.

Hopkins, William E.
1979a. Plant associations of south Chiloquin and Klamath Ranger Districts, Winema Natl. For. USDA For. Serv. R6-ECOL-79-005, 96 p., illus. Pac. Northwest Region 6, Portland, Oreg.

Hopkins, William E.
1979b. Plant associations of the Fremont National Forest. USDA For. Serv. R6-ECOL-79-004, 106 p., illus. Pac. Northwest Region 6, Portland, Oreg.

Howard, W. E., and H. E. Childs, Jr.
1959. Ecology of pocket gophers with emphasis on Thomomys bottae Mewa. Hilgardia 29(7):277-358.

Hull, A. C., Jr.
1971. Effects of spraying with 2,4-D upon abundance of pocket gophers in Franklin Basin, Idaho. J. Range Manage. 24(3):230-232.

Ingebo, P. A., and A. R. Hibbert.
1974. Runoff and erosion after brush suppression on the natural drainage watersheds in central Arizona. USDA For. Serv. Res. Note RM-275, 7 p., Rocky Mountain For. and Range Exp. Stn., Fort Collins, Colo.

Ingles, Lloyd G.
1973. Mammals of the Pacific States. 506 p., illus. Stanford Univ. Press, Stanford, Calif.

Keen, F. P.
1943. Ponderosa pine tree classes redefined. J. For. 41(4):249-253, illus.

Keen, F. P.
1952 (rev.). Insect enemies of western forests. U.S. Dep. Agric. Misc. Publ. 273, 280 p., illus.

Keith, J. O., R. M. Hansen, and A. L. Ward.
1959. Effect of 2,4-D on abundance of foods of pocket gophers. J. Wildl. Manage. 23(2):137-145.

Lawrence, William H.
1957. Porcupine control: A problem analysis. For. Res. Notes. 43 p. Weyerhaeuser Timber Co., For. Res. Center, Centralia, Wash.

Lightle, Paul C., and Melvyn J. Weiss.
1974. Dwarf mistletoe of ponderosa pine in the Southwest. USDA For. Serv. For. Pest Leafl. 19, 8 p., illus.

Little, Elbert L., Jr.
1953. Check list of native and naturalized trees of the United States (including Alaska). USDA Agric. Handb. 41, 472 p.

Little, Elbert L., Jr.
1971. Atlas of United States trees. Volume 1. Conifers and important hardwoods. UDSA For. Serv. Misc. Publ. 1146, 211 p.

Lynch, Donald W.
1958. Effects of stocking on site measurements and yield of second-growth ponderosa pine in the Inland Empire. USDA For. Serv. Res. Pap. 56, 36 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Mc Connell, Burt R., and Justin G. Smith.
1970. Response of understory vegetation to ponderosa pine thinning in eastern Washington. J. Range Manage. 23(3):208-212.

MacLean, Colin D., and Charles L. Bolsinger.
1973. Estimating productivity on sites with a low stocking capacity. USDA For. Serv. Res. Pap. PNW-152, 18 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Martin, Robert E., Dan D. Robinson, and Walter L. Schaeffer.
1976. Fire in the Pacific Northwest: Perspectives and problems. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 1-23. Tall Timbers Res. Stn., Tallahassee, Fla.

Martin, Robert E., and John D. Dell.
1978. Planning for prescribed burning in the inland Northwest. USDA For. Serv. Gen. Tech. Rep. PNW-76, 67 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Martin, Robert E., and Arlen H. Johnson.
1979. Fire management of Lava Beds National Monument. In Proc. First Conf. on Sci. Res. in National Parks, Vol. II, Nat. Park Serv. and Am. Inst. Biol. Sci., Washington, D.C. p. 1209-1218.

Martin, Robert E., and Jerry T. Williams.
1978. A timber type evaluation of historical Douglas-fir tussock moth outbreak areas in Oregon and Washington. USDA/DFTM R&D Program Final Rep., 45 p., illus.

Meyer, Walter H.
1934. Growth in selectively cut ponderosa pine forests of the Pacific Northwest. U.S. Dep. Agric. Tech. Bull. 407, 64 p., illus.

Meyer, Walter H.
1961. Yield of even-aged stands of ponderosa pine. U.S. Dep. Agric. Tech. Bull. 630, 59 p. (Revised.)

Mowat, E. L.
1950. Cutting lodgepole overstory releases ponderosa pine reproduction. J. For. 48(10):679-680.

Mowat, Edwin L.
1953. Thinning ponderosa pine in the Pacific Northwest--a summary of present information. USDA For. Serv. Res. Pap. 5, 24 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Mowat, Edwin L.
1961. Growth after partial cutting of ponderosa pine on permanent sample plots in eastern Oregon. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Pap. 44, 23 p., illus. Portland, Oreg.

Oliver, William W.
1979. Fifteen-year growth patterns after thinning a ponderosa-Jeffrey pine plantation in northeastern California. USDA For. Serv. Res. Pap., Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif. (In press).

Peterson, Roger S.
1960. Western gall rust on hard pines. USDA For. Serv., For. Pest. Leafl. 50, 8 p., illus.

Rochelle, James A., Illo Gauditz, Katashi Oita, and John H. K. Oh.
1974. New developments in big-game repellents. In Wildlife and Forest Management in the Pacific Northwest, p. 103-112, H. C. Black, ed. For. Res. Lab. Sch. For., Oreg. State Univ., Corvallis, Oreg.

Roth, Lewis F.
1959. Perennial infection of ponderosa pine by Elytroderma deformans. For. Sci. 5(2):182-191, illus.

Roth, Lewis F., Charles G. Shaw III, and Leonard Rolph.
1977. Marking ponderosa pine to combine commercial thinning and control of armillaria root rot. J. For. 75(10):644-647.

Russell, Kenelm W., Robert E. Wood, and Charles H. Driver.
1973. Fomes annosus stump infection in ponderosa pine sapling stands of eastern Washington. Wash. Dep. Nat. Res. Rep. No. 27, Olympia.

Salman, K. A., and J. W. Bongberg.
1942. Logging high-risk trees to control insects in the pine stands of northeastern California. J. For. 40(7):533-539.

Sartwell, Charles.
1971. Thinning ponderosa pine to prevent outbreaks of mountain pine beetle. In Precommercial thinning of coastal and intermountain forests in the Pacific Northwest, p. 41-52, illus., David M. Baumgartner, ed. Symp. Proc. Feb. 3-4, 1971, Coop. Ext. Serv. and Dep. For. and Range Manage., Wash. State Univ., Pullman.

Sartwell, Charles, and R. E. Dolph, Jr.
1976. Silvicultural and direct control of mountain pine beetle in second-growth ponderosa pine. USDA For. Serv. Res. Note PNW-268, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Sartwell, Charles, and R. E. Stevens.
1975. Mountain pine beetle in ponderosa pine: prospects for silvicultural control. J. For. 73(3):136-40.

Sassaman, Robert W., James W. Barrett, and Asa D. Twombly.
1977. Financial precommercial thinning guides for Northwest ponderosa pine stands. USDA For. Serv. Res. Pap. PNW-226, 27 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Schubert, Gilbert H.
1974. Silviculture of southwestern ponderosa pine: The status of our knowledge. USDA For. Serv. Res. Pap. RM-123, 71 p., illus. Rocky Mountain For. and Range Exp. Stn., Fort Collins, Colo.

Shaw, C. G. III.
1974. Epidemiological insights into Armillaria mellea root rot in a managed ponderosa pine forest. Ph.D. thesis. Oreg. State Univ., Corvallis.

Sikorowski, Peter P., and Lewis F. Roth.
1962. Elytroderma mycelium in the phloem of ponderosa pine. Phytopathology 52(4):332-336, illus.

Silen, Roy R., with Ivan Doig.
1976. The care and handling of the forest gene pool. Pac. Search 10(8):7-9.

Smith, David M.
1962. The practice of silviculture. 7th ed, 578 p., illus. John Wiley and Sons, Inc. New York and London.

Soeriaatmadja, R. E.
1966. Fire history of the ponderosa pine forests of Warm Springs Indian Reservation, Oregon. Ph.D. thesis. Oreg. State Univ., 132 p. Corvallis.

Sorensen, Frank C., and Richard S. Miles.
1974. Differential frost tolerance of ponderosa and lodgepole pine megasporangiate strobili. For. Sci. 20(4):377-378.

Sowder, James E.
1951. A sanitation-salvage cutting in ponderosa pine at the Pringle Falls Experimental Forest. USDA For. Serv. Res. Pap. 2, 24 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Spurr, Stephen H., and Burton V. Barnes.
1973. Forest ecology. 571 p., illus. The Ronald Press Co., New York.

Stewart, R. E., and T. Beebe.
1974. Survival of ponderosa pine seedlings following control of competing grasses. In Proc. West. Soc. Weed Sci. 27:55-58, illus.

Stoszek, Karel J.
1973. Damage to ponderosa pine plantations by the western pine shoot borer. J. For. 71(11):701-705.

Strand, M. A., and L. F. Roth.
1976. Simulation model for spread and intensification of western dwarf mistletoe in thinned stands of ponderosa pine saplings. Phytopathology 66(7):888-895.

U.S. Department of Agriculture, Forest Service.
1940. Annual report. Intermt. For. and Range Exp. Stn., Ogden, Utah.

U.S. Department of Agriculture, Forest Service.
1974. The outlook for timber in the United States. USDA For. Serv. For. Resour. Rep. No. 20, 374 p. Washington, D.C.

Volland, Leonard A.
1974. Relation of pocket gophers to plant communities in the pine region of central Oregon. In Wildlife and forest management in the Pacific Northwest, p. 149-166, Hugh C. Black, ed. Symp. Proc., For. Res. Lab. Sch. For., Oreg. State Univ., Corvallis.

Volland, Leonard A.
1976. Plant communities of the central Oregon pumice zone. USDA For. Serv. R6 Area Guide 4-2, 113 p. Pac. Northwest Region 6, Portland, Oreg.

Wang, Chi-Wu.
1977. Genetics of ponderosa pine. USDA For. Serv. Res. Pap. WO-34, 24 p., illus. Washington, D.C.

Weaver, Harold.
1959. Ecological changes in the ponderosa pine forest of the Warm Springs Indian Reservation in Oregon. J. For. 57(1):15-20.

Weaver, Harold.
1961. Ecological changes in the ponderosa pine forests of Cedar Valley in southern Washington. Ecology 42(2):416-420.

Woodfin, Richard O.
1978. Ponderosa pine lumber recovery--young growth in northern California. USDA For. Serv. Res. Pap. PNW-237, 13 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Wright, Henry A.
1978. The effect of fire on vegetation in ponderosa pine forests. A state-of-the-art review. Texas Tech. Univ. Range and Wildl. Info. Ser. No. 2, 21 p. Coll. Agric. Sci. Publ. No. T-9-199. Texas Tech. Univ., Dep. Range and Wildl. Manage., Lubbock.

Youngberg, C. T.
1966. Silvicultural benefits from brush. Soc. Am. For. Proc. 1965:55-59.

Youngberg, C. T.
1968. Effects of fertilization and thinning on the growth of ponderosa pine. Agron. Abstr. 140.

Youngberg, C. T.
1975. Effects of fertilization and thinning on the growth of ponderosa pine. Soil Sci. Soc. Proc. 39(1):137-139, illus.

APPENDIX

Table 11--Plants, diseases, insects, mammals, and birds[1/]

Common name	Scientific name
HERBS AND SHRUBS	
Bitterbrush, antelope	Purshia tridentata (Pursh) DC.
Bunchgrass	Agropyron sp.
Chinkapin	Castanopsis spp.
Golden	C. chrysophylla (Dougl.) A.DC.
Sierra	C. sempervirens (Kell.) Dudl.
Comandra, common	Comandra umbellata (L.) Nutt.
Fescue	Festuca sp.
Manzanita, greenleaf	Arctostaphylos patula Greene
Needlegrass	Stipa sp.
Ninebark	Physocarpus sp.
Oceanspray	Holodiscus sp.
Peavine	Lathyrus sp.
Sagebrush	Artemisia sp.
Sedge	Carex spp.
Elk	C. geyeri Boott
Ross	C. rossii Boott
Snowberry	Symphoricarpos sp.
Snowbrush	Ceanothus velutinus Dougl. ex Hook.
Squirreltail	Sitanion sp.
Wheatgrass	Agropyron sp.
Wildrye, blue	Elymus glaucus Buckl.
TREES	
Douglas-fir	Pseudotsuga menziesii (Mirb.) Franco
Fir, true	Abies spp.
Grand	A. grandis (Dougl.) Lindl.
White	A. concolor (Gord. & Glend.) Lindl.
Incense-cedar	Libocedrus decurrens Torr.
Pine	Pinus spp.
Jeffrey	P. jeffreyi Grev. & Balf.
Lodgepole	P. contorta Dougl.
Ponderosa	P. ponderosa Laws.
DISEASES	
Dwarf mistletoe	Arceuthobium spp.
Southwestern	A. vaginatum cryptopodum (Engelm.) Hawksw. & Wiens
Western	A. campylopodum Engelm.
Needle blight	
Elytroderma	Elytroderma deformans (Weir) Darker

DISEASES (Continued)	
Root rot	
Armillaria	Armillaria mellea (Vahl. ex Fr.) Quel.
Annosus	Fomes annosus (Fr.) Cke.
Rust	
Comandra	Cronartium comandrae Pk.
Western gall	Endocronartium harknessii (J.P. Moore) Y. Hirax
INSECTS	
Beetle	
Mountain pine	Dendroctonus ponderosae Hopkins
Turpentine	D. valens Le Conte
Western pine	D. brevicomis Le Conte
Borer, western pine shoot	Eucosma sonomana Kearfott
Butterfly, pine	Neophasia menapia (Felder and Felder)
Engraver, pine	Ips pini Say
Wasp, parasitic	Theronia atalantae (Poda)
MAMMALS	
Bobcat	Lynx rufus (Schreber)
Chipmunk	Eutamias spp.
Cougar	Felis concolor (Linnaeus)
Deermouse	Peromyscus spp.
Deer, mule	Odocoileus hemionus (Rafinesque)
Elk	Cervus spp.
Fisher	Martes pennanti (Erxleben)
Gopher, pocket	Thomomys talpoides (Richardson), T. mazama (Merriam)
Groundsquirrel, golden mantled	Callospermophilus spp.
Porcupine	Erethizon dorsatum (Linnaeus)
Squirrel, red	Tamiascurus spp.
Vole	Microtus spp.
BIRDS	
Chickadee, mountain	Parus gambeli Ridgway
Dove, mourning	Zenaidura macroura Linnaeus
Flicker, common	Colaptes auratus Linnaeus
Jay	
Pinon	Gymnorhinus cynocephalus Wied
Steller's	Cyanocitta stelleri Gmelin
Junco, dark-eyed	Junco hyemalis Linnaeus
Woodpecker, white-headed	Dendrocopos albolarvatus Cassin

1/ Nomenclature follows, for trees, Little (1953); for grasslike plants, forbs, and shrubs, Garrison and Skovlin (1976); for insects, Furniss and Carolin (1977); for mammals, Ingles (1973); and for birds, American Ornithologist's Union (1957).

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The Recreation Opportunity Spectrum: A Framework for Planning, Management, and Research

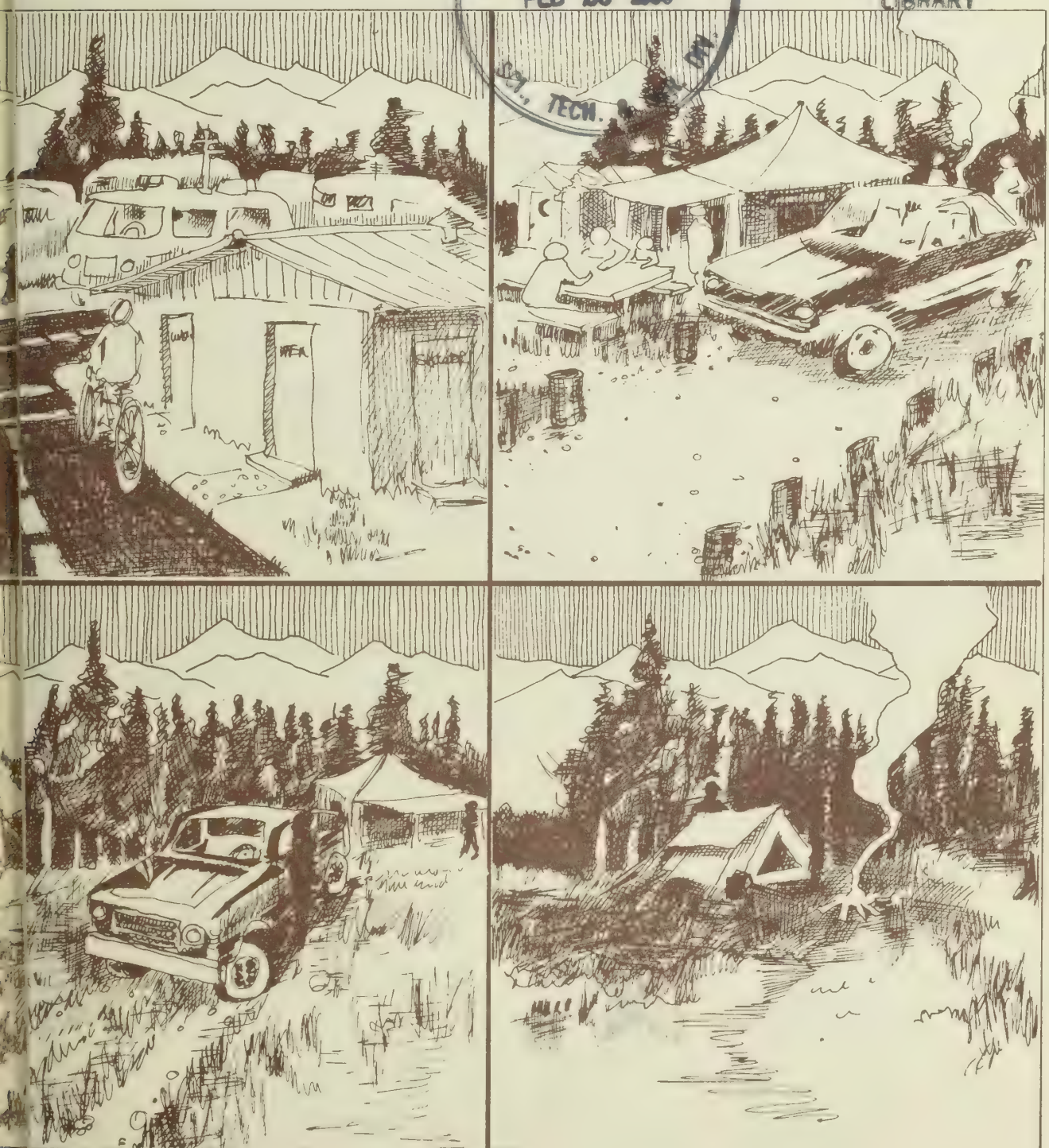
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Abstract

The end product of recreation management is a diverse range of opportunities from which people can derive various experiences. This paper offers a framework for managing recreation opportunities based on six physical, biological, social, and managerial factors that, when combined, can be utilized by recreationists to obtain diverse experiences.

Keywords: Recreation, land use, multiple use -)recreation, management planning (forest).

Metric Equivalents

1 acre = 0.4047 hectare
1 mile = 1.61 kilometers

PREFACE

In 1890, two alpine lakes on the east flank of the Cascade Range in Washington State--Little Kachess and Big Kachess--were accessible only by game trails and were used infrequently by people. The lakes (about 2 miles apart) were connected by a trout-filled stream. The area was rich in wildlife. Groves of trees many hundreds of years old were interspersed through the area. Human impacts were virtually non-existent; only a few people entered the area for recreational activities. Hunters and a few trappers were known to use the area on occasion. The Kachess area offered a true wilderness opportunity for those wishing to use it.

In the early 1900's, as part of its water program, the U.S. Bureau of Reclamation designated the Kachess drainage as a potential impoundment, and a dam was soon constructed. The water in the newly created lake reached its first high level in the spring of 1912. The resulting lake, known as Lake Kachess, was approximately 11 miles long and became an attraction for a variety of recreational activities. For the next several decades, the road system used for building the dam and for logging was expanded, facilitating access to recreational opportunities. Evidence of use became obvious as people camped and played along both the lakeshore and several streams that emptied into the recently completed lake. The primeval conditions that once characterized Lake Kachess were no longer present, but the people who came looking for semiprimitive types of recreation were apparently happy with what they found.

By the 1940's, use at Lake Kachess had increased markedly, and several camping areas had been established by users. Firepits abounded in favored spots, trails led to prime fishing locations, and vegetation had been trampled in frequently used areas. In response to these impacts, the USDA Forest Service, the agency responsible for managing the area adjacent to the lake, developed several sites that had been heavily used for recreation along the west side of the lake. Roads were improved and rustic tables and outhouses installed. Agency presence became more evident as fire prevention and directional signs and a list of Federal regulations regarding recreational use were posted. The area, now much more developed, appealed to people looking for some of the conveniences of modern living. Most were apparently happy with what they found.

In response to rapidly growing recreational use and the increasing impact on resources, the USDA Forest Service further modified the area in the early 1960's. Paved roads were developed within the campgrounds, a new camping area was constructed to accommodate the increasing number of travel trailers, and heavily used areas were closed to overnight camping. Parking barriers were also added to prevent cars from driving off established road systems. The 100-acre recreation complex included three separate camping areas with a total capacity for nearly 100 parties, and a mile-long nature trail. Most resemblance to a primitive area had disappeared by this time. Campers had the convenience of paved roads, modern toilets, and running water. Campers seeking modern kinds of camping opportunities came in ever-increasing numbers and were apparently happy with what they found.

As use increased, the USDA Forest Service further developed the area. New campsites brought the total to nearly 200. More flush toilets, permanent fireplaces, and concrete and wood tables were built. The access road, extending some 5 miles from Interstate 90, was widened and paved. By the late 1970's, Lake Kachess represented a modern, highly developed, intensively used recreation complex, readily accessible to large numbers of people. On a typical summer weekend, hundreds of recreationists enjoy a variety of pastimes.

The level of recreational activities in the Lake Kachess area has slowly evolved for more than three-quarters of a century from a primitive environment to a highly developed, modern setting for recreation. Several questions can be asked about this process of change: What opportunities for recreation was Lake Kachess best suited to provide? What range or mix of opportunities might be developed in conjunction with the Lake Kachess development? What effects have past management decisions had on opportunities for recreation in the area? How have the changes in the nature of the opportunity affected the kinds of experiences the area provides?

The scenario of recreational development at Lake Kachess is not uncommon. Many campground and recreational areas throughout the country have followed a similar pattern of development. Nor are the questions we raise unusual. In the following pages, we try to answer them.

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INTRODUCTION

Today, many agencies at Federal, State, and local levels are responding to the burgeoning demand for outdoor recreation. In addition, many private firms offer facilities and services for recreation, such as campgrounds, computerized reservation systems, and equipment rentals. With this expansion in the demand for recreational services has come a number of complex policy issues. What range and mix of opportunities should be provided and what are the roles of the various suppliers? Who can most effectively and efficiently serve public needs at national, regional, and local levels?

In this paper we describe a framework for outdoor recreation managers and policymakers who must answer questions concerning both the allocation and management of opportunities for recreation. This framework rests on the concept of the Recreation Opportunity Spectrum (ROS). It is distinguished by varying conditions, ranging from modern and developed to primitive and undeveloped, or as Nash (1973) succinctly phrased it, "from the paved to the primeval." We will review the background of the opportunity spectrum concept and how it has been used in the past; describe six manageable factors or setting attributes that influence the opportunities for recreation; and describe uses of the spectrum concept for identifying and measuring the consequences of alternative allocations of and management actions on opportunities for outdoor recreation.

THE RECREATION OPPORTUNITY SPECTRUM

In this paper we focus on the setting in which recreation occurs. When considering opportunities for outdoor recreation, people must make choices about activities in which to engage, settings in which to recreate, and kinds of recreation experiences to seek. We believe that, by describing the factors that influence or define the range of possible settings and by communicating this information to recreationists, they will be able to choose the experiences they desire.

We define a recreation opportunity setting as the combination of physical, biological, social, and managerial conditions that give value to a place. Thus, an opportunity includes qualities provided by nature (vegetation, landscape, topography, scenery), qualities associated with recreational use (levels and types of use), and conditions provided by management (developments, roads, regulations). By combining variations of these qualities and conditions, management can provide a variety of opportunities for recreationists (fig. 1).



Figure 1.--*A recreation opportunity setting includes features provided by nature or management and associated with recreational use.*

Recreation opportunity settings imply a choice for recreationists; people must be aware of the opportunities, and the opportunities must be comprised of conditions desired by recreationists. Thus, opportunities are a function of user preference and a product of management actions designed to provide desired settings and to make people aware of their existence.

We recognize that the recreational value of an opportunity is a function of the perceived ability of that opportunity to provide certain activities and experiences. Our definition focuses on the social, physical, and managerial attributes of settings, not on the psychological values that may be derived. The link between the setting and experiences or "psychological outcomes" (Driver and Brown 1978) is an issue to which we will turn shortly.

The basic concept underlying ROS is not new. Many authors have remarked that a range or continuum of opportunities is needed to efficiently serve diverse public tastes for recreation. Wagar (1966) called for campgrounds ranging from highly developed sites suitable for modern self-contained campers to remote locations accessible only to backpackers. Similar continua have been suggested for hunting (Potter et al. 1973), wildland areas (Marshall 1933, Lloyd and Fischer 1972, Helburn 1977, Driver and Brown 1978), and parks (Field 1976, McCool and Elmer 1975). All these continua are characterized by a range of conditions from modern to primitive.

The spectrum concept is also reflected in a variety of land management descriptions. A basic recommendation of the Outdoor Recreation Resources Review Commission (1962) was for classification of recreational resources along "a spectrum from areas suitable for high-density use to sparsely used extensive primitive areas."

To implement terms of the National Forest Management Act (NFMA) (U.S. Laws, Statutes, etc. 1976a), the USDA Forest Service published draft regulations that note, "a broad spectrum of dispersed and developed recreation opportunities... will be provided." Through provision of this spectrum, land management planners will best be able to offer the diversity deemed so important by NFMA. To develop operational guidelines for the implementation of the ROS, the USDA Forest Service has established a task force of managers and researchers.1/ This group will be responsible for development of procedures to apply the opportunity spectrum concept on the ground. The Bureau of Land Management, U.S. Department of the Interior, is similarly involved in developing such guidelines.

1/ Members of the task force include Thomas Hoots (Task Force Leader, Washington Office), John Asterford (San Bernadino National Forest), Wendell Beardsley (Northern Region, USDA Forest Service), Perry Brown (Colorado State University), Leon Buist (University of Nevada), Roger Clark (Pacific Northwest Forest and Range Experiment Station, USDA Forest Service), Charles McConnell (Rocky Mountain Region, USDA Forest Service), Gary Morrison (Mount Baker-Snoqualmie National Forest), George Olson (North Carolina National Forest), Doug Smith (Southwestern Region, USDA Forest Service), George Stankey (Intermountain Forest and Range Experiment Station, USDA Forest Service), Lance Tyler (Arapaho-Roosevelt National Forest), Donald Warman (Pacific Northwest Region, USDA Forest Service), Bev Driver (Rocky Mountain Forest and Range Experiment Station, USDA Forest Service).

The tabulation below further illustrates the spectrum concept as used in legislation, in land management planning procedures, and in user-oriented classifications of recreational opportunities, such as river running and mountain climbing. These examples are evidence of growing recognition by both managers and recreationists of the importance of diversity in settings for recreational opportunities.

Federal legislation:	
Wild and Scenic Rivers Act (U.S. Laws, Statutes, etc. 1976c)	Recognizes three classes of rivers varying in level of modification, development, and permitted activities
National Trails Act (U.S. Laws, Statutes, etc. 1976b)	Recognizes three classes of trails varying in purpose, permitted uses, and adjacent development
National Forest Management Act (U.S. Laws, Statutes, etc. 1976a)	Calls for providing a broad spectrum of dispersed and developed recreational opportunities
Federal agency planning:	
USDA Forest Service	Recognizes five recreation experience levels, ranging from those offering challenge, solitude, and demanding high skills to those involving extensive facilities and few skills.
Heritage Conservation and Recreation Services (formerly Bureau of Outdoor Recreation)	Recognizes six types of outdoor recreation settings ranging from class I (high density recreation areas) to class VI (historic and cultural sites)
Opportunity for recreation:	
River running (e.g. Arighi and Arighi 1974)	International scale of river difficulty recognizes six classes of conditions, ranging from class I (moving water with a few riffles and small waves, and no obstructions to class VI (nearly impossible, very dangerous)
Mountain climbing (e.g., Robbins 1971)	International Decimal System describes climbing skills ranging from class 1.0 (hiking) to class 5.0 to 5.11 (increasingly difficult piton-protected climbing)

DIVERSITY AND QUALITY IN OUTDOOR RECREATION

The basic assumption underlying the ROS is that quality in outdoor recreation is best assured through provision of a diverse set of opportunities. A wide range of tastes and preferences for recreational opportunities exists among the public and, as Wagar (1966) points out, "Quality seems to be a highly personalized matter." Providing a wide range of settings varying in level of development, access, and so forth insures that the broadest segment of the public will find quality recreational experiences, both now and in the future (fig. 2).

The importance of supplying diverse opportunities for camping has been illustrated by Wagar (1966). As he indicates, even a few different kinds of camping facilities greatly increase the probability of meeting more people' desires. If any generalization can be made from the body of knowledge about recreationists, it is that people vary enormously in what they desire from their recreational pursuits. This generalization is true, even for specific categories of recreationists; not all campers, hikers, or wilderness users are alike. Building management programs around average tastes can greatly miss the mark, because often such averages are statistical phenomena that do not adequately account for the wide variation in tastes (Shafer 1969).

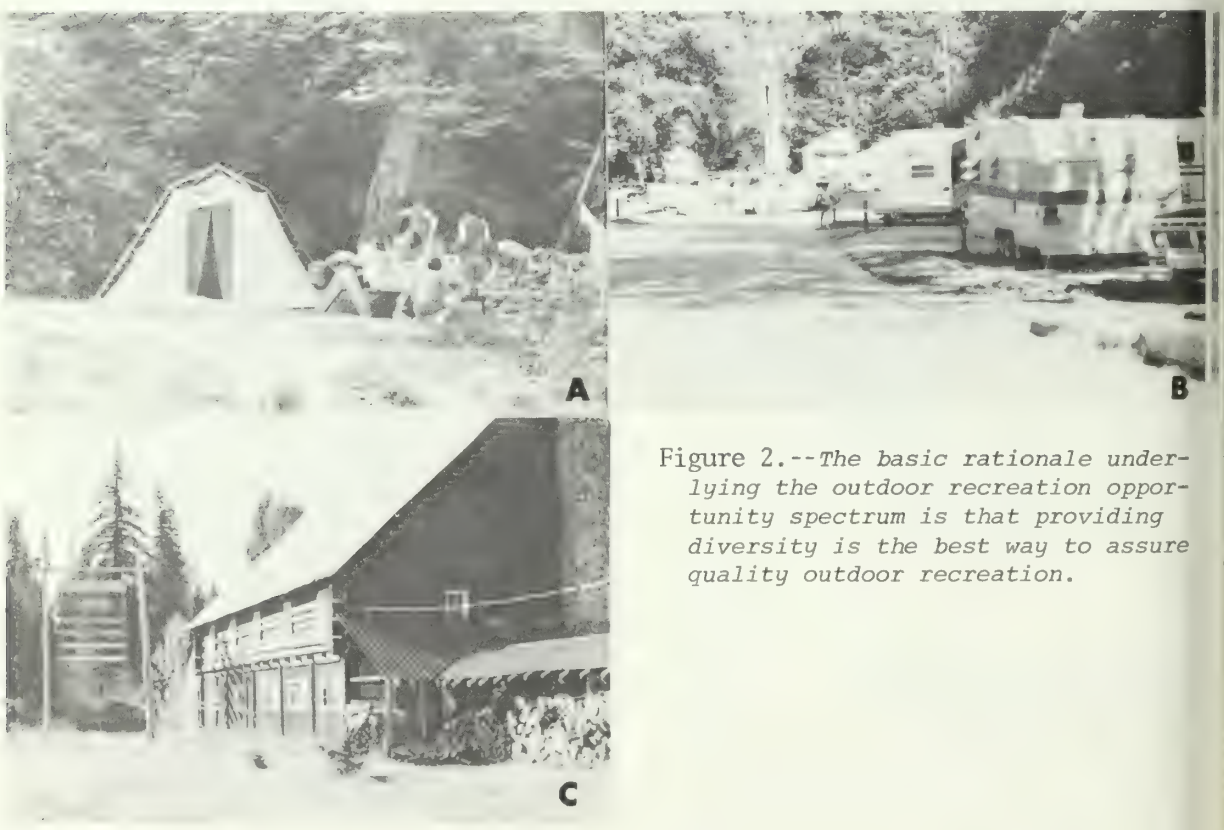


Figure 2.--*The basic rationale underlying the outdoor recreation opportunity spectrum is that providing diversity is the best way to assure quality outdoor recreation.*

Diversity represents an important characteristic of any recreation system. Managing opportunities for recreation to promote a diversity of experiences is crucial for social equity (Watt 1972). Failing to provide diversity of opportunity invites charges of favoritism, elitism, and discrimination. Further, diversity insures the flexibility necessary to mitigate changes or disturbances in the recreation system stemming from such factors as social change (changing age structure of U.S. population) or technological change (outdoor recreation vehicles, etc.).

But diversity is only a means to an end. Quality recreation, producing desired satisfactions and benefits for participants, is the objective and concern of both managers and recreationists. But what is quality? From an individual perspective, it is fairly easy to describe a quality recreational experience. For one person, it might be an extended backpacking trip in a very primitive area. For another, it might mean a camping trip in a motor home along a lightly used logging road. For yet another, a quality recreational experience may be camping in a 500-unit intensively developed campground where it is easy to visit with other people. Furthermore, the same person may find all these experiences enjoyable and of high quality at one time or another. Recreation is indeed a phenomenon in which quality is in the eye of the beholder.

The existence of different conceptions of quality does not mean that it is a meaningless concept; the provision of opportunities for quality outdoor recreation is a legitimate goal of recreation management. Quality is a relevant notion along the entire spectrum. Quality, then, is not judged by the presence or absence of some factor (facilities, naturalness, or other visitors), but as the extent to which a given setting satisfies the desires of a particular recreationist. The recreation opportunity spectrum helps clarify the quality issue by providing a framework that calls for the systematic provision of diverse settings for recreation (fig. 3).



Figure 3.--*The opportunity spectrum is not a quality continuum. Quality reflects the extent to which a setting meets the recreationists' desires and needs. Camping in a clearcut area is as satisfying to some people as camping in a wilderness is to others.*

THE LINK BETWEEN RECREATIONAL OPPORTUNITIES AND EXPERIENCES

Development of opportunities for recreation is not an end in itself. By providing different kinds of recreational settings and accommodating different types and styles of recreational use, managers can best give people the opportunity for various kinds of experiences.

Driver and Brown (1978) proposed a hierarchical framework that specifies four distinct levels of recreational demands: (1) for activities, (2) for certain situational attributes (settings), (3) for specific psychological outcomes--experiences and satisfactions and (4) for benefits. Our focus is primarily on level 2, the situational attributes that comprise a recreational opportunity. We concur with these authors that level 2 demands do not exist in and of themselves, but for the satisfactions and benefits derived at levels 3 and 4. Figure 4 shows the link between these levels of demand and the opportunities provided by managers.

Some gains have been made in the ability to define links between activities and outcomes (Driver and Tocher 1970, Brown et al. 1977, Potter et al. 1973). And it is clearly possible to facilitate the achievement of certain

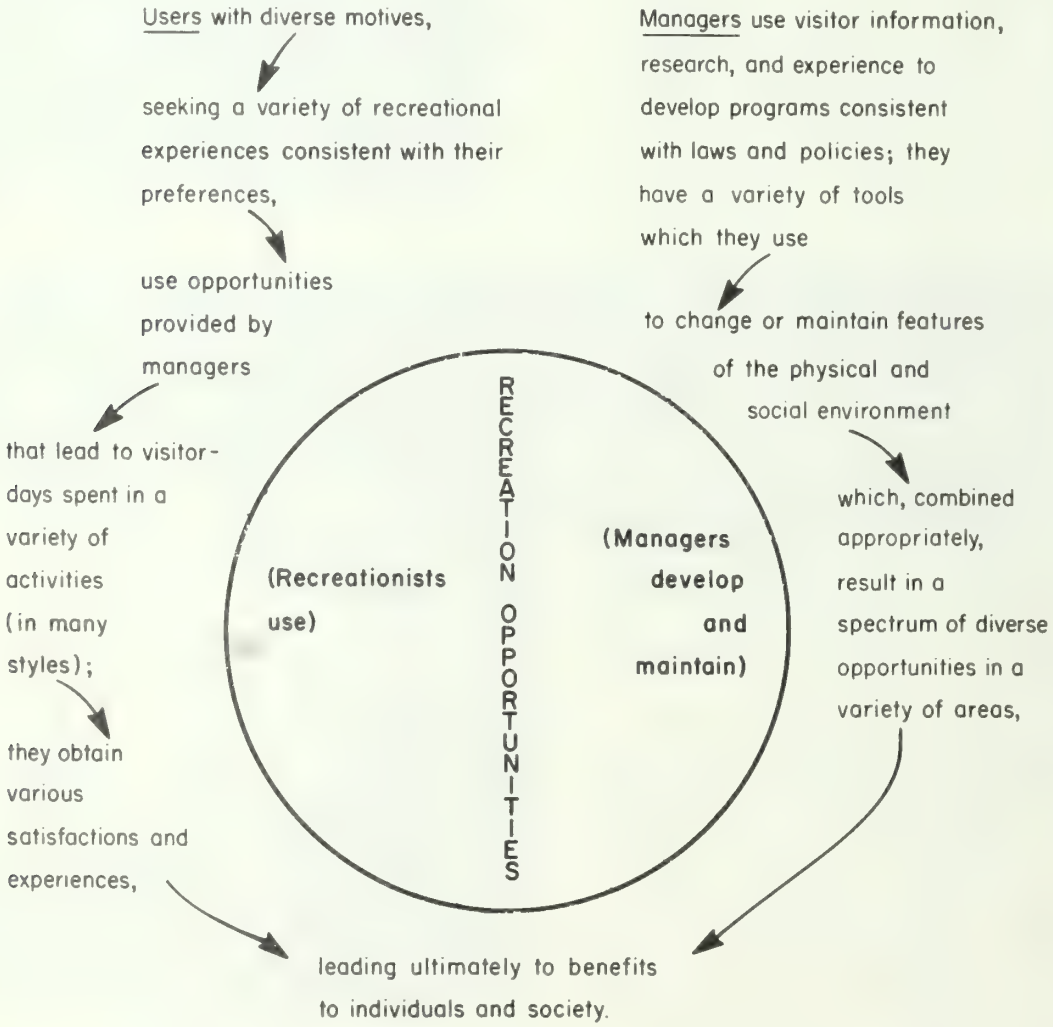


Figure 4.--*Link between recreationists' desires and the opportunities provided by managers.*

experiences by the way situational attributes are manipulated. Furthermore, by altering the setting, the same activity can be participated in in a variety of styles, thereby producing different satisfactions (fig. 5). As Knopp (1972) indicates, characteristics of a place will influence whether or not a given individual will recreate there, because the place is closely tied to the function of specific activities. As our knowledge of the linkage among settings, activities, experiences, and satisfactions improves, our ability to fine-tune the supply sector to most efficiently meet demands of visitors will grow.

Opportunities for recreation ought to differ in terms of producing distinctive experiences or "psychological outcomes" (Driver and Brown 1978). Work by a number of investigators increasingly improves the ability to do this (Lime 1971, Clark et al. 1971, Knopf et al. 1973, LaPage and Ragain 1974, Brown et al. 1977). Application of the opportunity spectrum framework outlined in the following pages, however, is not contingent on understanding the link between experiences (a psychological outcome) and opportunity settings. Simply put, the ROS can be used by managers to provide specific information to potential visitors about what a place is like, not about experiences they will derive.

The individual's choice of opportunity (or their expressed preference) provides feedback on the degree to which the opportunities might fulfill the desired outcomes. The specific experiences derived are a function of the individual's past experience, expectations, present state of mind, and so forth, not a function of an explicit management decision to produce a given outcome or set of outcomes.

ROS offers a framework within which to explicitly vary situational attributes (access, density, etc.) to produce different recreation opportunity settings. From these opportunity settings, recreationists participating in different kinds and styles of activities derive different satisfactions and experiences and, ultimately, benefits. Our intent here is to systematically and explicitly describe a framework that permits managers to provide diversity in the range of opportunity settings available to individuals.



Figure 5.--*Different activities can produce different experiences. But different styles of the same activity, carried out in various settings, can also produce different experiences.*

DEFINING OPPORTUNITY FACTORS

Four criteria were used to select factors that define the opportunity spectrum:

1. The factor is observable and measurable,
2. The factor is directly under management control,
3. The factor is related to recreationists' preferences and affects their decisions about areas to use, and
4. The factor is characterized by a range of conditions.

When these criteria were applied to existing conceptions of the ROS, previous research on recreationists' preferences, management experience, and state-of-the-art judgment, six factors emerged:

1. Access,
2. Other nonrecreational resource uses,
3. Onsite management,
4. Social interaction,
5. Acceptability of visitor impacts, and
6. Acceptable level of regimentation.

Each factor is described below. Natural features (topography, scenery,water, wildlife, etc.), which are important across the spectrum are discussed in a later section.

In this paper we describe the end points of the opportunity spectrum as modern to primitive. Other authors have used urban, developed, wild, natural, remote, etc. The labels are really unimportant and reflect authors' preferences rather than any conceptual difference between what we are proposing here and what is described in papers by others.

Opportunity Setting Factors

1. Access

Several elements can be used to describe access. Managers can control the ease of access by the types of access (e.g., roads, trails, cross-country travel) and by the means of conveyance allowed (e.g., cars, all-terrain vehicles, horses, feet). Both access elements can vary across the spectrum from easy to difficult. Design and management standards are important in defining the range of access systems. For example, roads and trails can be designed as high standard systems, requiring intensive maintenance, to low standard roads and trails needing little or no maintenance. In many cases, the topography and type of vegetation will help define the conveyances that can be used. Thus, managers are able to use a combination of natural features, design and maintenance standards, and regulations for determining and enforcing ease of access.

Research indicates that recreationists' preferences for alternative types of access cut across the range of access conditions (fig. 6). For example, among wilderness users, there is a spectrum of preferences for trails ranging from highly developed to no trails at all (Stankey 1973, Lucas 1973). Although users of forest lands with roads are there because they prefer a more primitive recreational setting than is typically found in developed campgrounds, they, too, vary in their preferences for paved or unpaved roads.2/

2/ Clark, Roger N. Russell W. Koch, Mack L. Hogans, and Harriet H. Christensen. Dispersed recreationists along forest roads in three areas of the Pacific Northwest: Their recreation patterns, opinions, and attitudes. Unpublished data on file at Pacific Northwest Forest and Range Experiment Station, Seattle, Washington.



Figure 6.--*Visitor preferences for access within recreation areas range from well-developed, paved roads, to gravel roads, to trails, to cross-country travel. Access also controls the type of conveyance recreationists may use.*

2. Nonrecreational resource uses

This factor considers the extent to which nonrecreational resource uses (grazing, mining, logging) are compatible with various opportunities for outdoor recreation. Other uses can severely conflict with opportunities for primitive experiences. For example, Stankey (1973) found that grazing in the Bridger Wilderness in Wyoming was the most serious source of conflict reported by visitors. In other cases, a variety of resource management activities that might even contribute to visitor enjoyment can be found in conjunction with outdoor recreation. For example, recreationists in semi-primitive areas with roads often find grazing and logging acceptable (see footnote 2). But these users do express concern about large clearcuts, so the scale at which the activity is conducted, as well as the activity itself, influences perceived compatibility (fig. 7). Planners and managers must consider the lasting effects of a resource activity (mines, clearcuts), as well as short-term effects (logging trucks, noise from a mine) to determine the impacts on the recreational opportunity.



Figure 7.--*Generally opportunities for primitive experiences are incompatible with nonrecreation resource uses. For example, timber harvests conflict with the kinds of experiences wilderness visitors seek. But in semiprimitive or semimodern areas with roads, clearcuts may be acceptable to some recreationists.*



Figure 8.--*Onsite management includes modifications, such as bridges, which can vary from simple logs for foot travel to complex developments capable of supporting automobiles.*



Figure 9.--*In modern settings, well-developed toilet facilities may be provided for convenience of visitors; in more rustic settings, they may be for safety of visitors or for protection of resources.*

3. Onsite management

The onsite management factor includes site modifications, such as facilities, exotic species of vegetation, vegetation management, landscaping, traffic barriers, etc. The appropriateness of site management should be considered in light of four elements:

a. Extent of the modification. Is it limited to a few isolated locations or distributed throughout the area?

b. Apparentness of the modification. Has the use of native materials helped blend the modification into the natural setting or do artificial materials make the modification readily apparent?

c. Complexity of the modification. A bridge could be a simple log footpath (fig. 8) or a complicated engineering effort.

d. Facilities. Facilities can be largely for convenience and enjoyment or safety of users, or only for protection of the resources. In some areas, no facilities whatsoever are appropriat in others, all possible conveniences would be appropriate. Toilet facilitie can range from heated buildings with flush toilets and showers, to pit toilets, or, in some settings, to no toilet facilities at all (fig. 9).

4. Social interaction

The appropriate amount of social interaction is an important characteristic of different recreational opportunities. Generally, in more primitive settings, low levels of interaction are appropriate and expected. In more modern settings, interaction can rise to very high levels. The level of use beyond which crowding occurs, then, is not absolute but varies by expectations of visitors and the extent to which interaction levels are perceived as appropriate (fig. 10). Insufficient levels of interaction in some modern settings can be just as unacceptable to some people as excessive levels in primitive settings (Heberlein 1977).

Both natural variations (topography and vegetation patterns) or management actions (access) can greatly influence the actual level of contact among people. Consequently, standard measures of density (number of people or parties per unit area) are inappropriate because they fail to consider the potential for contact between people. The number of people in an area, how they are distributed in space and time, and the probability of interaction between parties are important elements in determining the appropriate social carrying capacities at different points along the opportunity spectrum. Although the recreation opportunity spectrum will not give a specific number for the carrying capacity of a specific opportunity type, the basic concepts underlying the framework help in resolving the carrying capacity issue. Managers and planners must apply these concepts on an area-by-area basis.

Appropriate levels of interaction vary along the spectrum; they can also vary for the same physical setting defined as a different kind of recreational opportunity. For example, for travelers on the Rogue River in Oregon who defined the area as wilderness, appropriate daily levels of contact averaged 2.6; for those who perceived the river as a semiwilderness setting, 4.4; and for those who defined the river as an undeveloped recreation area, 7.0.[3/]

In addition to the level of interaction, managers must also give attention to the type of use appropriate for each setting. Generally speaking, there is greater diversity of activities possible in modern settings than in primitive. Such factors as access may account for some of this difference; for example, in the most primitive setting, travel is by foot, but farther along the spectrum, travel by horses, outdoor recreational vehicles, and automobiles becomes appropriate. In the most modern setting, all types of groups and activities might be acceptable.

It is necessary to consider the acceptable diversity of use because interaction alone is not a sufficient measure of an area's social carrying capacity; the types of use found at a particular setting may be more important in defining capacity than the amount of use. Lucas (1964) found that canoeists in the Boundary Water Canoe Area thought that up to five encounters per day with other canoeists was acceptable, but even one contact with a motorboat was not acceptable. There are probably many reasons why this variable pattern of acceptability occurs (perceived inappropriateness of use, experience, or values), but the central implication for management is that a greater diversity of uses can be accommodated in modern settings than in primitive.

[3/] Presentation made by Dr. Bo Shelby, Oregon State University, Corvallis, at the Rural Sociology Society Annual Meeting in San Francisco in 1978.



Figure 10.--*In primitive settings, any other people might represent crowding; in modern settings, large numbers are acceptable. Crowding is a relative measure; there are no absolute standards.*

5. Acceptability of visitor impacts [4/]

Human use of resources inevitably results in impacts, and recreation is no exception. These impacts might be on resources (trampling of vegetation or polluting of water) or on other people (noise, depreciative behaviors, inappropriate activities). Any use creates some impact; thus, the relevant question for managers is not "how can impacts be prevented" but "what level of impact is consistent with the type of opportunity being supplied."

The acceptable level of impacts on recreation is a concern to both users and managers. Managers must be concerned about maintaining opportunities for quality recreation, as well as protecting other resource values. Research indicates that managers' perception of what constitutes impacts may be very different (generally more conservative) from users' perceptions (Clark et al. 1971, Bultena and Hendee 1972, Downing and Clark 1979, Lucas 1970). When users' perceptions are considered, acceptable impacts take on a range of conditions across the ROS.

Two concepts are useful in resolving how much impact is appropriate. In assessing environmental impacts, one should consider both magnitude and importance. The magnitude of impacts is based on an objective assessment--there should be no substantive disagreement on the magnitude of the impact. The importance of environmental impacts is based on a value judgment which can result, however, in considerable disagreement between managers and recreationists, depending on expectations, knowledge, and points of view of each group. It is the professional's responsibility to insure that objective measurement procedures are used to determine the magnitude of environmental impacts resulting from recreational use. It is also a professional responsibility to provide accurate assessments of the kinds of impacts stemming from recreational use, their implications for the environment and solutions to their management. But the importance of impacts must be considered in light of the desired opportunity and subsequent impacts on people's experiences. As noted above, total prevention of impacts is impossible, short of complete prohibition of recreational use.

Thus, damage or a level of impact necessitating correction by management occurs only when the impact exceeds the magnitude defined in area management plans as appropriate for an opportunity level. The level of impact defined as damage in an area managed for modern opportunities will be quite different from that in the same area managed for primitive opportunities. Definitions of impact as "damage," then, depend on the type of opportunity or context in which they occur, rather than on any absolute measure. Generally, recreationists' tolerances for impacts (ecological, social, or managerial) are greater among modern styles of recreation than among primitive styles in both degree and prevalence.

6. Acceptable regimentation

The nature, extent, and level of control over recreational use is an important factor characterizing different opportunities. A continuum of controls can be described, ranging from subtle techniques--such as site design and providing visitors with information to fairly heavy-handed measures that are authoritarian and perhaps accompanied by legal sanctions (Lime 1976). Specific techniques for regimenting recreationists' activities include regulations, rules, side design, and laws.

[4/] See Clark and Stankey (1979) for discussion of the acceptability of recreation impacts, noise in particular.

Modern opportunities are generally characterized as more highly organized and regulated than are primitive types. But the "principle of minimum regimentation" should apply across the spectrum; we should regiment only as much as necessary to protect the qualities of the opportunity in question (Stankey and Baden 1977).

Ideally, the most primitive opportunities should have few regimenting influences. With the reality of increasing pressures from use of primitive settings, regimentation may be necessary to protect the integrity of the opportunity and to insure its use into the future. This is particularly true where management objectives call for the preservation of naturalness. Thus, management actions that might otherwise be appropriate for protecting an area (facilities, onsite management) would not be satisfactory if they themselves would alter natural integrity. Control of visitation would be necessary, and such measures have been instituted in several Wilderness Areas and in National Park back country (Stankey 1979, Fazio and Gilbert 1974).

POSSIBLE COMBINATIONS OF FACTORS

In figure 11, each factor is displayed graphically. The range of conditions that a factor can have (for example, from very easy to very difficult access), represents relative rather than absolute limits of what is acceptable and appropriate along the ROS. Certainly, when the framework is applied, specific criteria must be developed. Our objective, however, is to focus on the process by which the ROS factors can be managed to achieve desired objectives in a conceptual fashion. After the reader understands the approach, then more specific values for each factor can be estimated. Readers are encouraged to review Driver and Brown (1978) and Brown et al. (1978) for examples of proposed criteria developed for recreation inventory purposes. Information for selecting management objectives is found in Brown (1977).

A recreation opportunity setting is the result of a specific combination of the six factors in a particular location Alternative combinations of the factors (and other natural features discussed later) create different opportunity settings that give recreationists many options from which to choose. Considerations about appropriate criteria for any one of the factors are largely judgmental; there are seldom absolute standards.

There are no obvious points at which boundaries for the different opportunities can be established. For purely illustrative reasons, we use four generic opportunity types in the discussion below. But any number of categories could be substituted across the top of figure 11. For example, modern-urban, semirural, rural, semiprimitive motorized, semiprimitive nonmotorized, and primitive as used by Driver and Brown (1978). The key is that the type of setting is determined by the combination of factors, rather than the name or number of categories.

Existing knowledge about visitors' preferences, managers' judgments, and public involvement can help guide development of appropriate opportunity setting categories. By packaging recreational settings in terms of the six factors we have described, we can begin to explicitly develop a range of opportunities to better meet public desires.

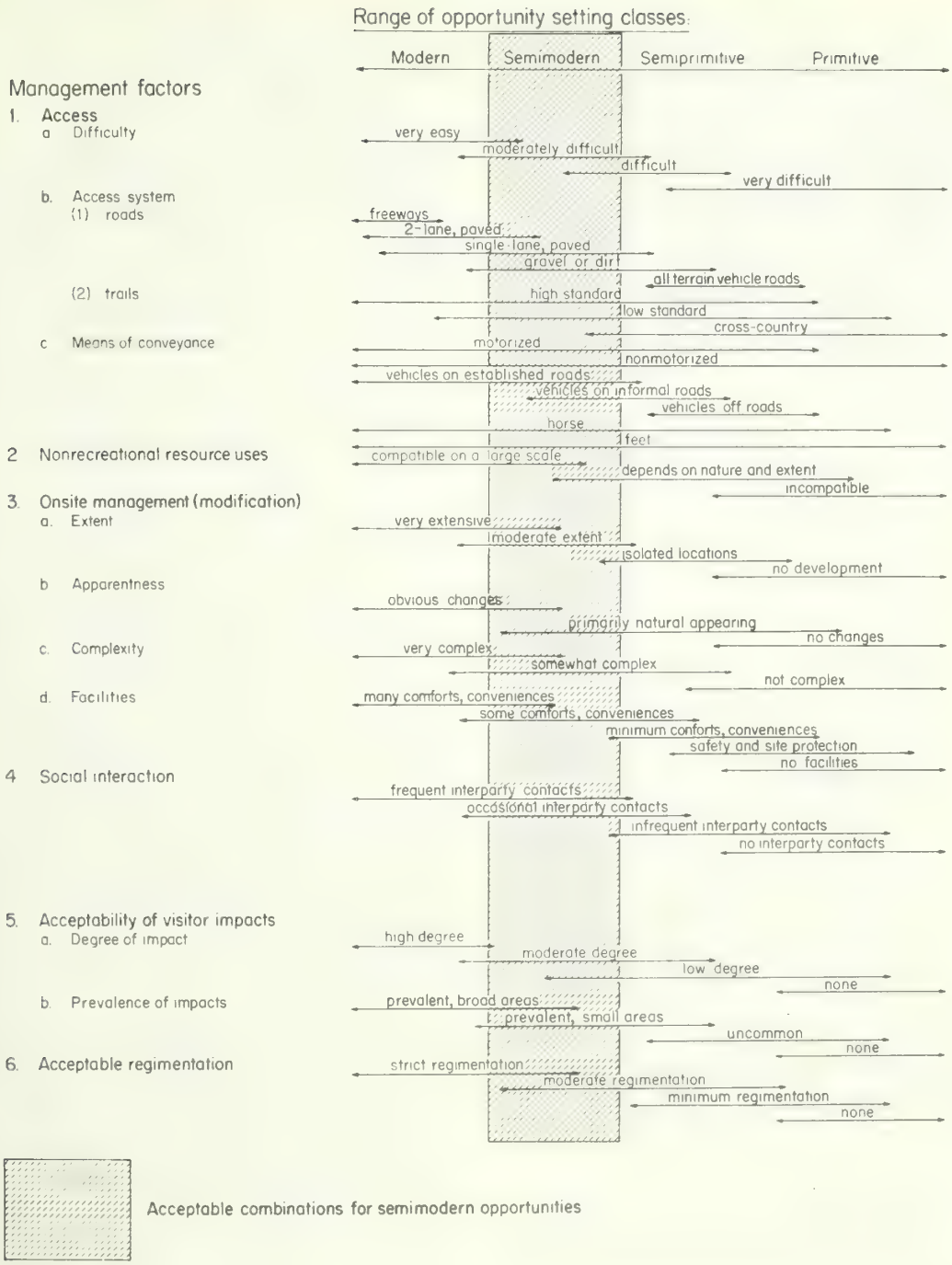


Figure 11.--*Factors defining outdoor recreation opportunity settings.*

In this discussion, we assume that all the factors have coequal weight; they all influence recreational behavior in the same way. In reality, we are sure that this is not the case. For some people, type of access might be the most important influence. For others, it might be the type of facilities, or the nature of previous visitor impacts, etc. When choices of recreation in general, are considered however, such individual differences may balance out. Further research will be required to determine under what conditions this assumption is appropriate.

An approach for combining the factors is shown in figure 11. All the conditions represented by the six factors are arrayed along the modern to primitive opportunity continuum. For any generic type of opportunity--modern, semimodern, etc.--a band of acceptable combinations can be described in area management plans through the use of objectives and standards.

In figure 11, for example, we show a band of acceptable combinations for the semimodern types of opportunities. This band simply means that any of the conditions within the range indicated for the six factors are acceptable in an area managed as semimodern. Anything outside the band would be unacceptable. We will talk more about conditions outside the band of acceptability in the section, "Inconsistencies."

It should be clear that, although we describe only four generic opportunity types here, each represents many possible combinations of the six factors. It is important that we provide diversity, not only between opportunity types but also within individual types. For example, semimodern opportunity settings might include sites where access, facilities, and so forth are relatively highly developed; other settings might have developed facilities but be accessible only by foot or bicycle; still others might feature a rustic setting reached by gravel roads, but with extensive site modification to minimize impacts on the resources. The point is, designation of an opportunity as "semimodern", "primitive", etc., does not imply a single standard of development for areas within that category. Variations in settings within and among opportunity types within a band of acceptability further increases the rang of options for recreationists pursuing different types and styles of activities

Other Features of Settings

We have mentioned several times that a recreation opportunity setting is composed of other natural features in addition to the six factors. Landform types, vegetation, scenery, water, wildlife, etc., are all important elements of recreation environments; they influence where people go and the kinds of activities possible. Considerable work has gone into developing procedures for measuring and managing visual resources (USDA Forest Service 1974). Planners and managers should also consider these features when determining for which types of opportunity to manage an area.

But it is important to recognize that there is no intrinsic quality of these other natural features that suggests the appropriate type of recreation opportunity setting. Any of the opportunity types are as possible and appropriate in mountainous areas as they are in desert settings. Indeed, greatest diversity would be assured if the full spectrum of opportunity types (modern to primitive) could be found across the range of environmental settings (fig. 12).

Environmental settings	Opportunity types			
	Modern	Semi-modern	Semi-primitive	Primitive
Mountains	All possible combinations are appropriate			
Rivers				
Lakes				
Deserts				
Etc				

Figure 12.--*Appropriate combinations of opportunity types and environmental settings.*

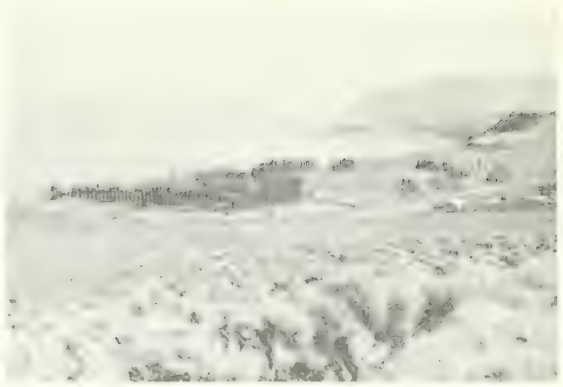


Figure 13.--*There is nothing intrinsic in the landscape to dictate the best type of opportunity. Modern opportunities in an alpine setting are needed as much as primitive opportunities in deserts or plains.*

And it is the combination of these environmental settings and opportunity types that determines the range of allowable recreational activities in a specific area. The nature of participation in recreational activities depends on the place in which it occurs (Cheek et al. 1976). Thus, natural features (terrain, rivers, lakes) will influence the activities that are possible; for example, you cannot waterski without a relatively large body of water. The type of opportunity for which the area is managed, however, will help determine the appropriateness and styles of activities. It is inappropriate to expect to be able to waterski in primitive areas, even if there is a large body of water and one could get a powerboat there. Conversely, it would be inappropriate for a backpacker to expect to find a low level of social interaction in a highly developed, modern campground (fig. 13).

Inconsistencies

One important issue that must be considered when specific opportunity settings are being developed is the avoidance of inconsistencies. An inconsistency occurs when the status of a factor (or factors) exceeds the parameters specified in the area management plan; for example, Brown et al. (1978) propose a series of standards for selected criteria that define appropriate conditions for different opportunity types. Although their criteria differ somewhat from ours, their process is identical. By specifying standards for the range of appropriate conditions for a given type of opportunity, managers have a rational basis for determining inconsistencies. Formulation of appropriate standards combines information from research, public input, administrative policies, legislative guidelines, and managers' judgments. Examples of standards would include such things as standards for constructing highways and trails, frequency and type of user interaction, types and amounts of facilities, and other specific onsite management actions.

In some cases, laws or policies provide guidelines for what is appropriate (no mechanized access is permitted in Wilderness Areas). More commonly, managers must rely on other guidelines. Studies of recreationists' preferences or other measures of appropriateness can help identify the factors that users define as consistently related. In other cases, managers will be able to use the ROS framework to identify potential undesirable consequences that would follow from an inconsistent combination of factors.

For example, when access roads along the southern edge of the Boundary Waters Canoe Area were paved and straightened, levels of use rose rapidly (much as they did at Lake Kachess). Following this change in the access factor, pressures developed for increased facilities and other measures to control use--developments generally inconsistent with primitive type opportunity and so recognized by land managers, recreationists, and the Wilderness Act (fig. 14).

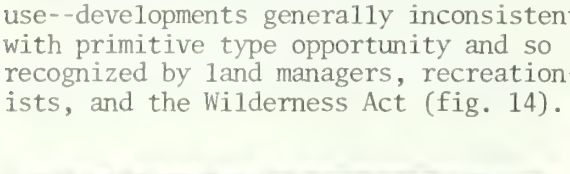


Figure 14.--*A road used to reach the timber near wilderness is now used by increasing numbers of recreationists. This may lead to increased need for facilities and more regimentation.*

The opportunity spectrum does not offer a prescribed formula for providing outdoor recreation opportunities. It does provide a systematic framework for looking at the actual distribution of opportunities and a logical procedure for assessing possible management action. To demonstrate how one might use the framework to test for consistency, we present the following example:

For illustrative purposes, we have shown within the band of acceptability the relative range of conditions one might describe as a "semimodern" opportunity (fig. 11). Such an opportunity could be characterized in general by relatively well-developed access roads, extensive development of facilities for both resource protection and visitor convenience, relatively high densities of users and social interaction, etc. Thus, the opportunity setting has all six factors approximately equal in their position along a modern to primitive continuum; i.e., there is a "consistency" among the various factors within the band of acceptability.

But what if one or more factors is outside the band of acceptability? In figure 15 the overall pattern suggests that the area has potential as a supplier of a primitive type opportunity; however, access to the area is well developed along paved roads (in the "modern" category). Thus, an apparent inconsistency exists. If an objective of the opportunity spectrum concept is to minimize the effects of inconsistencies, a series of questions concerning the apparent inconsistency can be asked.

Management factors	Recreation opportunity types (X = existing condition for the management factors)			
	Modern	Semimodern	Semiprimitive	Primitive
1. Access	X			
2. Nonrecreational resource uses				X
3. Onsite management				X
4. Social interaction			X	
5. Acceptable impacts				X
6. Regimentation			X	

Figure 15.--*An example of an inconsistency.*

How did the inconsistency occur? A variety of causes could be responsible for the inconsistency. It might result from an earlier management action (e.g., roadbuilding for timber harvest), for which the effects on recreational use were never identified or anticipated. Had these effects been recognized, the road might not have been built, the type of construction or the road's location might have been changed, or perhaps the road would have been closed after the timber was removed.

Or, the impacts on recreation of an earlier action might have been identified and considered but judged to be unavoidable. Such a situation might develop where the anticipated benefits seem to outweigh costs (the benefit of a timber harvest exceeding the costs incurred by changing the nature of the recreational opportunity). Perhaps different administrative jurisdictions were involved, one controlling the management action, the other the recreational opportunity. Even though the latter jurisdiction had fully identified anticipated impacts, it did not control the management action and was thus unable to influence the other organization's decision.

Finally, the inconsistency could be the result of a purposeful course of action. The apparently inconsistent factor might, in fact, be more in line with the kind of opportunity most needed in the area. For example, there might be plans to convert the generally primitive opportunity in figure 15 to a semimodern opportunity where relatively easy access is desirable. This conversion could be based on an assessment that the relative availability of primitive opportunities in the region is high, whereas the supply of semimodern opportunities is low. Or it might be that an apparent inconsistency is required to achieve certain objectives; it may be desirable to provide a primitive setting with some form of modern access to allow easy entry for the handicapped or to provide cabins for protection in primitive areas with dangerous bears.

What are the implications of the inconsistency? Consistency as we describe it above is an ideal concept. In reality, one or more factors may be inconsistent with the others. It is not the inconsistency per se that should be of concern; rather, the consequences of the inconsistencies constitute the problem, particularly when they are not anticipated or recognized.

In the early 1900's, the Lake Kachess campground was a primitive setting. Access was difficult and use was light. But over the ensuing three-quarters of a century, a number of changes altered Lake Kachess. Improved access made it possible for greater numbers of people to reach the area. Management concerns with overuse (both resource impacts and crowding) led to development of various facilities (tent pads, vault toilets, parking areas) and other onsite modifications. Each action at Lake Kachess changed the nature of the opportunity the area provided. Yet visitors still filled the campground. Clearly there was no optimum environment for recreation at the lake; nor is it possible to say that current conditions are either better or worse than they once were. But they certainly are different.

Our purpose in describing the evolution of events at Lake Kachess is not to cite it as an unnatural situation nor to suggest that one particular set of conditions was better than another. Rather, it is to illustrate the consequences stemming from the lack of precise management objectives and an explicit monitoring and evaluation process. As problems arise and management responds to them in an effort to correct or offset impacts, inconsistencies may result and a chain reaction of secondary changes can occur,

ultimately altering the entire nature of the original opportunity. The principal implication of the Lake Kachess example is that the process of change was largely inadvertent and that most of the changes were the result of reactions to problems rather than a deliberate and conscious effort to alter the kind of opportunity the area provided.

Serious problems can develop from inadvertent changes. As the nature of a setting is altered, inconsistencies may occur, resulting in subsequent changes in use. The "new" campground attracts a different type of user, camping in a different style and seeking different kinds of experiences. As the new type of user becomes increasingly established, original users move to other locations more to their liking; that is, where the combination of all opportunity factors (including access, use density, and facilities) still resembles the kind of opportunity formerly enjoyed. This process of "invasion and succession" (Clark et al. 1971) can drastically change the nature of the available opportunities, the clientele served, and their recreational experiences. Particularly where the process is unnoticed, opportunities can be lost and clientele disfranchised.

Given inconsistencies such as those that occured at Lake Kachess, managers must answer the question, What are the implications associated with the factors for both themselves and the users? Part of the answer to this question rests on how far out of line the factor apparently is. It is obvious that a factor only moderately out of line (e.g., density and regimentation in fig. 15) has less significant implications than one substantially inconsistent with the remaining factors (e.g., access). Managers must make judgments about the importance of these inconsistencies.

Implications for managers might involve questions, such as: Will the inconsistency accelerate change in other factors that will, in turn, lead to further undesired changes in the kind of opportunity provided (such as at Lake Kachess)? For example, will the highly developed access shown in figure 15 lead to higher levels of resource impact because of increased use at the site and necessitate development of more facilities or further regulation of use? And, if these outcomes appear likely, are they desirable or undesirable?

It is important to remember that we are looking at recreation as a system, with an interdependence among the various elements of that system. Thus, a change or modification in one element may affect (perhaps slowly or very quickly) the other parts of the system. Remoteness from humans and their impacts, for example, is a major consideration in primitive settings. But the level of remoteness can be affected by changes in several management factors--access, social interaction, and nonrecreational resource uses. Changes in any one factor may lead to an inconsistency resulting in a negative impact on other factors. Consequently, remoteness in an area managed for primitive values may be reduced below acceptable limits.

The basic problem of an inconsistency is that it introduces the potential for triggering a chain of events that might alter the entire nature of the intended opportunity. When such a situation develops, rapid changes in the distribution and use of opportunities can occur.

What should be done about inconsistencies? When inconsistencies occur, managers have three basic responses available. First, a "no action" response can be adopted. This might be the case if no significant effects are anticipated, at least within the foreseeable future. Or jurisdictional problems between agencies or functional problems within an agency may mean the inconsistency cannot be directly controlled by recreation managers; for example, planned changes in the access to an area by one government agency might affect adjacent recreation lands managed by another agency. Offsetting the problems brought about by these changes might involve such measures as site modifications, development of facilities, and regimental controls--actions whose costs outweigh any benefit they might have.

A second response is to restore the inconsistency to a status in line with the parameters specified for it. Closures of certain types of roads, elimination of facilities, or other onsite modifications might be instituted to restore consistency.

Finally, managers can respond to an inconsistency by altering the remaining factors to bring them into line with the original inconsistent one. This could occur where changing conditions of demand call for an opportunity not presently provided. Response to a situation where well-developed access is inconsistent with a primitive type opportunity might involve altering the remaining factors to make the area semimodern. Such a change would have its justification outlined in the area management plan.

USING THE RECREATION OPPORTUNITY SPECTRUM

At the broadest level, the ROS offers a way of thinking about opportunities for recreation, of considering recreation as something more than activities or areas. But beyond this, the opportunity spectrum has specific application for at least four major concerns: (1) allocating and planning recreational resources, (2) inventorying recreational resources, (3) estimating the consequences of management decisions on recreational opportunities, and (4) matching experiences recreationists desire with available opportunities.

Allocating and Planning Recreational Resources

The ROS is a helpful concept for determining the types of recreational opportunities that should be provided. And after a basic decision has been made about the opportunity desirable in an area, the ROS provides guidance about appropriate planning approaches--standards by which each factor should be managed.

Three concepts related to the ROS are useful in making such decision: (1) the relative availability of different opportunities, (2) their reproducibility, and (3) their spatial distribution.

Relative availability, although not directly manageable by any one recreation supplier, is a fundamental consideration affecting decisions about the opportunities that should be provided. The concept addresses the issue of supply as well as the appropriate role of the recreation supplier. Adequacy of supply is a function of, among other things, the spatial distribution of opportunities,

and it may be appropriate to estimate relative availability within a regional framework that extends beyond agency boundaries. When one type of opportunity is in abundant supply, it may be necessary for an agency to provide alternative opportunities even though these are not normally a responsibility of the agency. For example, the USDA Forest Service recreation program emphasizes the provision of opportunities for dispersed recreation. In an area like southeast Alaska, however, where such opportunities are abundant and the USDA Forest Service manages most of the land, the agency might find it necessary to also provide modern and semimodern opportunities in the interests of offering diversity (Clark and Lucas 1978) (fig. 16).



Figure 16.--*The role of the private sector will be especially important in areas where the public sector is not a major supplier of certain opportunities.*

Reproducibility and reversibility are also fundamental considerations. They address the question of the extent to which an opportunity can be technologically reproduced, as well as the ability of management to reverse the outcome of decisions. Opportunities at the modern (developed) end of the spectrum are generally more reproducible (capable of creation through use of technology, infusion of capital, etc.) than those at the primitive end. There is a test of reasonableness here, because it is at least possible to reproduce any opportunity, given sufficient time and money. The spectrum is characterized by asymmetry in the reversibility of management actions because changes from modern to primitive can be more easily reversed than changes in the other direction (fig. 17). The obvious implication here is that decisions transforming an area from a primitive condition to something more developed needs to be carefully weighed because of the relative inability to reverse that decision.



Figure 17.--*Through use of capital, design, and engineering, modern opportunities can be more readily created than can primitive settings which are a product of natural processes.*

In planning and managing large areas for recreational purposes, managers must consider the spatial distribution of opportunities (fig. 18). Sharply dissimilar opportunities generally should be kept apart so that conflicts are minimized (Hart 1966, Gould 1961, Stankey 1974, Clawson 1975)



Figure 18.-- *Sharply dissimilar opportunities should be separated. Conflicts between mechanized and nonmechanized use, for example, can seriously interfere with the experiences of both users. Spatial zoning can help reduce such conflicts.*

For example, opportunities featuring high standard road systems and highly developed campgrounds should not be constructed adjacent to primitive opportunities. Keeping dissimilar opportunities apart also reduces the likelihood that impacts from one opportunity will "spill over" onto an adjacent opportunity (e.g., noise from an area catering to outdoor recreational vehicle users reaching an adjacent area managed for primitive opportunities). Some recent planning efforts have attempted to incorporate this concept; the recently dedicated Alpine Lakes Wilderness in Washington's Cascade Range will be bordered by a management area featuring primarily semiprimitive recreational opportunities.

Unfortunately, planners and managers often do not have the necessary flexibility to organize opportunities according to this ideal spatial arrangement. They are constrained by previous management decisions, other resource uses, established recreational use, or a variety of other factors that complicate the job. But even within these limitations, mapping recreational opportunities--existing and proposed--can help identify potential conflicts.

Inventory of Recreational Opportunities

The ROS provides a useful framework for the review and evaluation of inventory data (for a good review of various recreation inventory systems, see Brown et al. 1978). Because the ROS focuses on specific situational attributes (access, facilities, etc.) that comprise recreation opportunity settings, managers easily can relate inventory data to the spectrum. From this, the relative availability of different settings can be determined. Moreover, because of the focus on situational attributes, managers will be able to tell how they could change the relative availability of different settings. For example, if semimodern settings were in short supply, the inventory could indicate areas where such settings could be most easily created.

Inventories should encompass at least regional levels and transcend administrative boundaries. Ideally, the goal should be to insure that recreation opportunity suppliers--public and private--collectively provide a range of diverse opportunities. This clearly calls for interorganizational coordination in inventory of planning for recreational opportunities.

A comprehensive inventory conducted at a regional scale and involving all public and private suppliers would provide several critical pieces of information: (1) a profile of existing and potential opportunities; (2) a catalog of administrative responsibilities (i.e., who has which opportunities); and (3) an indication of the spatial relationships between various opportunities for recreation (thereby suggesting the potential for conflicts or complementary relationships). Additionally, when such inventory data are combined with studies of recreation demand and preference, it may be

possible to determine gaps in the distribution of opportunities that ought to be filled. Conversely, such information could reveal which opportunities are in excess supply.

Inventory data compiled over a regional setting is critical data in the formulation of appropriate roles for the various suppliers. Seldom will any one supplier be capable of meeting the entire range of recreation opportunity demands. Data about existing and potential opportunities, who manages them, and their location would be important input to decisions about who is best equipped to fulfill which roles. The USDA Forest Service recently completed an analysis of its appropriate role in the provision of opportunities for outdoor recreation (USDA Forest Service 1977). This study is based on assessment of the kinds of opportunities the agency has under its jurisdiction, as well as on such things as expertise, legislative direction, and so forth.

Identifying the Consequences of Management Actions

Because the recreation opportunity spectrum focuses on specific features of the physical, social, and managerial setting, it facilitates analysis of how proposed management actions will alter the nature of a specific opportunity.

For example, the decision to develop an area for timber harvest has the obvious consequence of changing the level and obtrusiveness of nonrecreational resource uses. But logging also often alters the amount and type of access into an area. This improved access, in turn, can lead to higher use and greater demand for facilities. Many of these changes can be anticipated, however, and the ROS provides a simple, graphic way of portraying these anticipated outcomes and evaluating whether or not they are appropriate or desirable.

Such an approach means that explicit recognition of changes affecting the opportunity spectrum is assured. By providing a framework in which the consequences of different decisions can be considered in relation to how they affect opportunities for recreation and their use, many undesirable problems related to functional decisionmaking (about logging, road development, etc.) can be anticipated and possibly avoided.

The key to using the ROS effectively is the area's management plan. Only with clearly specified management objectives is it possible to say whether the consequences of an action are acceptable and appropriate or not. Management without such objectives can only be reactive.

Matching Desired Experiences With Available Opportunities

Matching the experiences visitors seek with opportunity settings best suited to providing those experiences is one of the major challenges to the outdoor recreation manager. We often assume this requires direct management actions, whereby managers know who wants what and direct recreationists accordingly. But without good information about the various types of experiences recreationists seek, this is a hopeless task. To further complicate matters, there is no simple link between experiences sought, recreation activities, and opportunity settings.

One approach that does not rely on a prior knowledge of desired experiences is to upgrade the flow of information to people about the nature and location of existing opportunity settings. At present, recreationists' lack of knowledge about existing opportunities is sometimes as great a deterrent to participation as is the actual unavailability of opportunities (fig. 19



Figure 19.-- *Providing visitors with information about available alternatives may be one of the most effective actions open to recreation managers. From descriptions of opportunities, visitors can choose the setting that seems to best meet their particular desires.*

If the recreationists are given information about the various opportunities, they can then choose the most appropriate locations for their particular types and styles of activity. For example, recreationists' interests in driving for pleasure (a type of activity) might range from looking at fall leaf colors along a modern paved highway to four-wheel driving off roads.

Several examples of efforts to improve information to users can be cited. On the Suislaw National Forest in Oregon, managers have described five types of camping experiences available, ranging from remote wilderness to highly developed settings. They have not only identified what is available on National Forest lands but also included opportunities provided by other agencies, such as highly developed campgrounds in State parks. After selecting experiences desired, visitors can examine a listing of available campgrounds in the area, categorized by the type of opportunity provided. This approach also gives managers a chance to measure demand for the various opportunities and, if necessary, to make adjustments in their supply (relative availability) to more accurately reflect the actual demand. Using this approach effectively requires, at a minimum, that managers have a complete and regularly updated inventory of various opportunities in their areas (including those supplied by other agencies).

This approach assumes that people do know, in general, the characteristics of the recreation opportunity setting they prefer or dislike. Thus, management ought to strive to provide recreationists with information about such things as the level of interparty contact, access, or facilities they may find at any given site. Through a trial-and-error process, recreationists can find what suits them best.

Managers can also use predictable, seasonal changes at specific locations to provide diverse opportunities for recreationists. For example, many campgrounds have been developed to provide modern experiences during the summer season of peak use (June through August). These campgrounds are often in spectacular locations that have year-round appeal. Frequently, however, they are closed from August to June (and even on weekdays during the summer season, in some instances). Such closures concentrate use into a relatively short season and eliminate the potential for off-season use.

Natural processes can also alter the opportunities available even in open areas--snowfall may preclude access by conventional, wheeled vehicles, thereby converting a modern opportunity to a more primitive one for part of the year. Such changes, whether by management or natural processes, affect one or more of the opportunity factors and thereby change the opportunity available. Utilizing these seasonal changes, management can provide variety at individual sites, thereby extending use throughout the year, gaining greater use of expensive recreational developments, and broadening the range of options from which visitors can choose (fig. 20).



Figure 20.-- *One way to provide additional opportunities for recreationists is to encourage off-season use of settings. For example, summer use of developed ski areas for picnicking, sightseeing, etc., provides a different opportunity for visitors, even though the same area is involved.*

We believe that the key to matching the experiences users desire with available opportunities is to let users make their own choices based on reliable information about the opportunities available. Such information, aimed at creating realistic expectations, should be about the nature of the opportunities, where they are, and how conditions might change throughout the year.

CONCLUSIONS

The recreation opportunity spectrum provides a framework for integrating recreational opportunities and nonrecreational activities. The central notion of the spectrum is to offer recreationists alternative settings in which they can derive a variety of experiences. Because the management factors that give recreational value to a site are interdependent, management must strive to maintain consistency among these factors so that unplanned or undesired changes in the opportunities do not occur.

In this paper we focused primarily on existing social conditions and technology. But, technology and socioeconomic changes often produce impacts beyond the ability of managers to fully anticipate or control. For example, few people anticipated the enormous growth in outdoor recreational vehicles that has occurred in the past decade. Similarly, the consequences of scarce energy resources were not foreseen until the scarcity was already a fact (Shafer et al. 1974). The impact of the changing age structure of the U.S. population has yet to be fully recognized (Marcin and Lime 1977). Such changes can produce dramatic shifts in the type and intensity of demand for opportunities for outdoor recreation. Although the future can be only imperfectly predicted, the ROS does provide a framework for accommodating these shifting demands, as well as estimating the kinds of impacts associated with these changes.

If a full range of opportunity settings is provided, changes in demand can be more easily accommodated because the kinds of features an activity requires are more likely to be available. Although the supply to meet the increased demand might be insufficient, nonetheless some areas with the necessary features should be available. Management of the full opportunity spectrum should permit accommodation of these changes with minimum disruption. Providing opportunities for quality recreational experiences means providing sufficient opportunities across the spectrum. Diversity is the key to meeting this challenge.

There may be an insufficient supply of the opportunities needed to meet changing demands, however, and managers may wish to consider increasing the supply. Such an increase will probably take place at the expense of some other

opportunity setting. The outdoor recreation opportunity spectrum provides a framework for identifying some of the consequences (social impacts) of such a decision. By identifying which specific opportunity factors will be altered and how, we gain knowledge regarding the changing distribution of opportunities, which clientele groups may be affected, the relative availability of alternative settings to meet these people's needs, and the extent to which a proposed alteration may result in a loss of settings formerly available. To allow such an assessment of change requires the routine collection of sufficient baseline information to document the types and amounts of recreational use occurring. Only after the change has been documented can managers rationally determine the most appropriate course of action.

RESEARCH NEEDS

The ROS framework described in this paper is based on state-of-the-art judgments. As such, the relationships we describe are tentative and need further verification; however, we believe that the framework offers a useful approach founded in management reality as well as research on visitors' attitudes and actual behavior. New information from research will aid full development of the outdoor recreation opportunity spectrum. This research should take several directions.

First, further investigations of the relationship between activities, settings, and experiences are needed. Specific efforts to define the psychological outcomes associated with different activity-setting combinations would help reveal how management can better help visitors achieve a diversity of experiences (e.g., see Brown et al. (1977) for an example of this in hunting). Such data would also be useful in defining boundaries between the generic opportunity classes.

Second, how are people's taste for recreational settings and activities shaped by the available supply? Are preferences merely a reflection of opportunity? If not, how can latent demand be identified to better fill out the opportunity spectrum?

Third, to what extent does substitutability exist among the various experiences recreationists seek? Are experiences uniquely linked to certain settings or activities? If not, what is the nature of the interchangeability (Field 1976, Hendee and Burdge 1974, Christensen and Yoesting 1979)? How do differences in style account for differences in the satisfactions received (e.g., what differences, if any, exist between hunting big game, upland-birds, or waterfowl in terms of the satisfactions participants seek)?

Fourth, and related to the earlier concerns with estimating demand, we need a better understanding of how tastes in recreation evolve over time. Are there orderly and predictable evolutions in tastes along the spectrum of settings? If so, how do persons at different stages in this evolution differ in terms of the experiences, activities, and settings they seek (Bryan 1977, 1979)? Does early exposure to modern opportunities lead to a demand for increasingly more primitive styles--do people learn as they recreate and seek more demanding settings and activities to refine their skills (Davidson et al. 1966)?

Finally, there is a need for research on the analysis of policy on such questions as: What are the appropriate roles for the various suppliers to adopt? What role should the private sector undertake and how might this vary across the country? What incentives might promote private development?

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LITERATURE CITED

Arighi, Scott, and Margaret S. Arighi.
1974. Wildwater touring. MacMillan Publ. Co., Inc., New York.

Brown, P. J., B. L. Driver, and C. McConnell.
1978. The opportunity spectrum concept and behavioral information in outdoor recreation resource supply inventories: Background and application. *In* Integrated inventories of renewable natural resources: Proceedings of the workshop. Gyde H. Lund, Vernon J. LaBau, Peter F. Ffolliott, and David W. Robinson, tech. coords. USDA For. Serv. Gen. Tech. Rep. RM-55, p. 73-84. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Brown, Perry J.
1977. Information needs for river recreation planning and management. *In* Proceedings: River recreation management and research symposium. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 193-201. North Cent. For. Exp. Stn., Minneapolis, Minn.

Brown, Perry J., Jacob E. Hautaluoma, and S. Morton McPhail.
1977. Colorado deer hunting experiences. 42d North Am. Wildl. and Nat. Resour. Conf. Trans., p. 216-225. Atlanta, Ga.

Bryan, Hobson.
1977. Leisure value systems and recreational specialization: The case of trout fishermen. J. Leisure Res. 9(3):174-187.

Bryan, Hobson.
1979. Conflict in the great outdoors: Toward understanding and managing for diverse sportsmen preferences. Sociol. Stud. 4, 98 p. Bur. Public Adm. Univ. Ala. Ala.

Bultena, Gordon L., and John C. Hendee.
1972. Foresters views of interest group positions on forest policy. J. For. 70(6):337-342.

Cheek, Neil H., Jr., Donald R. Field, and Rabel J. Burdge.
1976. Leisure and recreation places. 172 p. Ann Arbor Sci. Publ., Inc., Ann Arbor, Mich.

Christensen, James E., and Dean R. Yoesting.
1979. The substitutability concept: A need for further development. J. Leisure Res. 9(3):188-207.

Clark, Roger N., John C. Hendee, and Frederick L. Campbell.
1971. Values, behaviors, and conflict in modern camping culture. J. Leisure Res. 3(3):143-159.

Clark, Roger N., and Robert C. Lucas.
1978. The forest ecosystem of southeast Alaska: No. 10, Outdoor recreation and scenic resources. USDA For. Serv. Gen. Tech. Rep. PNW-66, 116 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Clark, Roger N., and George H. Stankey
1979. Determining the acceptability of recreation impacts: An application of the Outdoor Recreation Opportunity Spectrum. *In* Proceedings of the Wildland Recreation Impacts Conference, October 27-29, 1978, Seattle, Wash. Ruth Ittner, Dale R. Potter, and James K. Agee, eds. USDA For. Serv. and Natl. Park Serv., Pac. Northwest Reg.

Clawson, Marion.
1975. Conflicts and strategies in forest land management. J. Soil and Water Conserv. 30(2):63-67.

Davidson, Paul, F. Gerard Adams, and Joseph Seneca.
1966. The social value of water recreational facilities resulting from an improvement in water quality: The Delaware estuary. *In* Water research, p. 175-211. Allen V. Knesse and Stephen C. Smith, eds. Johns Hopkins Univ. Press, Baltimore.

Downing, Kent, and Roger N. Clark.
1979. User's and manager's perceptions of dispersed recreation impacts: A focus on roaded forest lands. *In* Proceedings of the Wildland Recreation Impacts Conference, October 27-29, 1978, Seattle, Wash. Ruth Ittner, Dale R. Potter, and James K. Agee, eds. USDA For. Serv. and Natl. Park Serv., Pac. Northwest Reg.

Driver, B. L., and Perry J. Brown.
1978. The opportunity spectrum concept and behavior information in outdoor recreation resource supply inventories: A rationale. *In* Integrated inventories of renewable natural resources: Proceedings of the workshop. Gyde H. Lund, Vernon J. LaBau, Peter F. Ffolliott, and David W. Robinson, tech. coords. USDA For. Serv. Gen. Tech. Rep. RM-55, p. 24-31. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Driver, B. L., and Ross Tocher.
1970. Toward a behavioral interpretation of recreational engagements, with implications for planning. *In* Elements of outdoor recreation planning, p. 9-31. B. L. Driver, ed. Ann Arbor, Mich.

Fazio, James R., and Douglas L. Gilbert.
1974. Mandatory wilderness permits: Some indications of success. J. For. 72(12):753-756.

Field, Donald R.
1976. Interchangeability of parks with other leisure settings. *In* Research in the parks transaction of the National Park centennial symposium. Annu. Meet. Am. Assoc. Adv. Sci., December 28-29, 1971, p. 159-168. Natl. Park Serv. Symp. Ser. 1.

Gould, Ernest M., Jr.
1961. Planning a recreational complex. Am. For. 67(8):30-35.

Hart, William J.
1966. A systems approach to park planning. Int. Union Conserv. Nat. and Natl. Resour. Suppl. Pap. 4, 118 p. Morges, Switzerland.

Heberlein, Thomas A.
1977. Density, crowding, and satisfaction: Sociological studies for determining carrying capacities. *In* Proceedings: River recreation management and research symposium. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 67-76. North Cent. For. Exp. Stn., Minneapolis, Minn.

Helburn, Nick.
1977. The wilderness continuum. Prof. Geogr. 29(4):333-337.

Hendee, John C., and Rable J. Burdge.
1974. The substitutability concept: Implications for recreation research and management. J. Leisure Res. 6(2):155-162.

Knopf, Richard C., B. L. Driver, and John R. Bassatt.
1973. Motivations for fishing. *In* Human dimensions in wildlife programs, p. 28-41. J. Hendee and C. Schoenfeld, eds. Wildl. Manage. Inst., Washington, D.C.

Knopp, Timothy B.
1972. Environmental determinants of recreation behavior. J. Leisure Res. 4(2):129-138.

LaPage, Wilbur F., and Dale P. Ragain.
1974. Family camping trends--an eight-year panel study. J. Leisure Res. 6(2):101-112.

Lime, David W.
1971. Factors influencing campground use in the Superior National Forest in Minnesota. USDA For. Serv. Res. Paper NC-60, p. 18, illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Lime, David W.
1976. Principles of recreational carrying capacity. *In* Proceedings of Southern States recreation research applications. USDA For. Serv. Gen. Tech. Rep. SE-9, p. 122-134. Southeast For. Exp. Stn., Asheville, N.C.

Lloyd, R. Duane, and Virlis L. Fischer
1972. Dispersed versus concentrated recreation as forest policy. 16 p. Proc. 17th World For. Congr., Bueno Aires, Argentina.

Lucas, Robert C.
1964. Wilderness perception and use The example of the Boundary Waters Canoe Area. Nat. Res. J. 3(3):384-411.

Lucas, Robert C.
1970. User evaluation of campground on two Michigan National Forests. USDA For. Serv. Res. Pap. NC-44, 15 p., illus. North Cent. For. Exp Stn., St. Paul, Minn.

Lucas, Robert C.
1973. Wilderness: A management framework. J. Soil and Water Conse 28(4):150-154.

McCool, Stephen F., and J. Stanley Elm
1975. Providing recreational opportunities through state park systems Utah Tourism and Recreation Rev. 4(3):1-5.

Marcin, Thomas C., and David W. Lime.
1977. Our changing population structure: What will it mean for future outdoor recreation use? *In* Outdoor recreation: Advances in application of economics. Jay M. Hughes and R. Duane Lloyd, compilers. USDA For. Serv. Gen. Tech. Rep. WO-2, p. 42-53. Washington, D.C.

Marshall, Robert.
1933. The forest for recreation. *In* A national plan for American forestry. A report prepared by the Forest Service in response to S. Res. 175 (72d Congress) Senate Document 12, Separate 6, p. 463-487. U.S. Gov. Print. Off.

Nash, Roderick.
1973. Wilderness and the American mind. 300 p. Yale Univ. Press, New Haven.

Outdoor Recreation Resources Review Commission.
1962. Outdoor recreation for America. 246 p. Washington, D.c.

Potter, Dale R., John C. Hendee, and Roger N. Clark.
1973. Hunting satisfaction: Game, guns, or nature? Proceeding 39th North Am. Wildl. Conf. Proc. p. 220-229. Washington, D.C.

Robbins, Royal.
1971. Basic rockcraft. 71 p. La Siesta Press, Glendale, Calif.

Shafer, Elwood L.
1969. The average camper who doesn't exist. USDA For. Serv. Res. Pap. NE-142, 27 p., illus. Northeast. For. Exp. Stn., Upper Darby, Pa.

Shafer, Elwood L., George Moeller, and Russell E, Getty.
1974. Future leisure environments. USDA For. Serv. Res. Pap. NE-301, 14 p., illus. Northeast. For. Exp. Stn., Upper Darby, Pa.

Stankey, George H.
1973. Visitor perception of wilderness recreation carrying capacity. USDA For. Serv. Res. Pap. INT-142, 61 p., illus. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Stankey, George H.
1974. Criteria for the determination of recreational carrying capacity in Colorado River Basin. *In* Environmental management in the Colorado River Basin, p. 82-89. A. Berry Crawford and Dean F. Peterson, eds. Utah State Univ. Press, Logan.

Stankey, George H.
1979. Use rationing in two southern California wildernesses. J. For. 77(6):347-349.

Stankey, George H., and John Baden.
1977. Rationing wilderness use: Methods, problems, and guidelines. USDA For. Serv. Res. Pap. INT-192, 20 p., illus. Intermt. For. and Range Exp. Stn., Ogden, Utah.

U.S. Department of Agriculture, Forest Service.
1974. The visual management system. *In* National Forest landscape management. Agric. Handb. 2(462):1-47. U.S. Gov. Print. Off., Washington, D.C.

U.S. Department of Agriculture, Forest Service.
1977. The Forest Service roles in outdoor recreation. U.S. Dep. Agric. Program Aid 1205, 13 p.

U.S. Laws, Statutes, etc.
1976a. National Forest Management Act of 1976. This Act calls for development of guidelines for land management that will provide for a diversity of plant and animal communities. Public Law 94-588. In its United States statutes at large. 1976. 90 Stat.:2949. (16 USC 1600.). U.S. Gov. Print. Off., Washington, D.C.

U.S. Laws, Statutes, etc.
1976b. National Trails Act of 1968. An Act that recognizes three classes of trails varying in purpose, permitted uses and adjacent development. Public Law 90-543. In its United States statutes at large. 1968. 82 Stat.:919. (16 USC 1241.) U.S. Gov. Print. Off., Washington, D.C.

U.S. Laws, Statutes, etc.
1976c. Wild and Scenic Rivers Act of 1968. An Act that recognizes three classes of rivers varying in level of modification, development and permitted activities. Public Law 90-542. In its United States statutes at large. 1968. 82 Stat.: 906. (16 USC 1271.). U.S. Gov. Print. Off., Washington, D.C.

Wagar, J. Alan.
1966. Campgrounds for many tastes. USDA For. Serv. Res. Pap. INT-6, 10 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Watt, Kenneth E. F.
1972. Man's efficient rush toward deadly dullness. Nat. His. 81(2): 74-77, 80, 82.

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ABSTRACT

Geomorphic and edaphic habitats in rangelands provide specialized habitats for some species of vertebrate wildlife. These habitats and how they function as specialized habitat features are examined. The relationships of the wildlife of the Great Basin to such features are detailed.

KEYWORDS: Wildlife habitat, geomorphology, edaphic relations, range management, Oregon (Great Basin).

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This publication is part of the series **Wildlife Habitats in Managed Rangelands — The Great Basin of Southeastern Oregon**. The purpose of the series is to provide a range manager with the necessary information on wildlife and its relationship to habitat conditions in managed rangelands in order that the manager may make fully informed decisions.

The information in this series is specific to the Great Basin of Southeastern Oregon and is generally applicable to the shrub-steppe areas of the Western United States. The principles and processes described, however, are generally applicable to all managed rangelands. The purpose of the series is to provide specific information for a particular area but in doing so to develop a process for considering the welfare of wildlife when range management decisions are made.

The series is composed of 14 separate publications designed to form a comprehensive whole. Although each part will be an independent treatment of a specific subject, when combined in sequence, the individual parts will be as chapters in a book.

Individual parts will be printed as they become available. In this way the information will be more quickly available to potential users. This means, however, that the sequence of printing will not be in the same order as the final organization of the separates into a comprehensive whole.

A list of the publications in the series, their current availability, and their final organization is shown on the inside back cover of this publication.

Wildlife Habitats in Managed Rangelands — The Great Basin of Southeastern Oregon is a cooperative effort of the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, and United States Department of the Interior, Bureau of Land Management.

Introduction

The Great Basin of southeastern Oregon is predominantly gentle in topography and monotonous in appearance. To many people, the region is bleak and desolate. It is a land of almost constant wind, of hot summers and cold winters, of dramatic contrasts in climate and in topography.

Physiographic features, such as cliffs (fig. 1), caves, and sand dunes, provide diversity in an otherwise homogeneous landscape; this diversity attracts people for a variety of reasons.

People rafting down the Owyhee River, for example, may be awed by the stark, silent beauty of the massive surrounding cliffs. But they may look at the cliffs without appreciation of what they represent, for they are unaware of the myriad of habitats that a cliff provides for vertebrate wildlife. Although they may see a prairie falcon land on a rock pinnacle, they do not see the white-throated swift nest under a loose, vertical slab of rock high on the cliff face and are unaware of the western pipistrelle, the canyon mouse, or the bushy-tailed woodrat deep in the crevices.[1]

They may not know that, without the cliffs, many species of wildlife would no longer inhabit the area. And they are perhaps not consciously aware that their primary attraction to the area was the beauty, contrast, and uniqueness of the cliffs.

[1]For scientific names of wildlife, see appendix 2.



Figure 1.—Cliffs, rising abruptly out of a relatively gentle landscape, concentrate a diverse fauna. People are attracted to such features by their beauty and by the wildlife that inhabit them. Other attractions include human artifacts and mineral deposits (photo courtesy Bureau of Land Management).

With a broad awareness and understanding of particular physiographic features, one begins to appreciate them as wildlife habitat, their relationship to land management, and the need to account for them in land use planning. Our purpose is to describe such physiographic features of the Great Basin and to examine them as habitats for wildlife.

Physiographic features are either geomorphic or edaphic. Geomorphic features are products of geologic or geomorphic processes and include cliffs, caves, talus, lava flows, sand dunes, and playas. Edaphic features are local, distinctive soils that, along with their vegetation, contrast markedly with the surrounding area.

There are two appendixes. Appendix 1 is a synopsis of physiographic features that displays how each species of vertebrate wildlife uses those features. In addition, species specifically adapted to particular features for part or all of their habitat requirements are identified. Appendix 2 is a phylogenetic list of the vertebrate species by common name and scientific binomial; it lists the references we used in preparing appendix 1.

Cliffs

Cliffs are steep, vertical, or overhanging rock faces that create abrupt changes in the land surface and form distinctive landscape features. Cliffs are composed of rock materials that are divided into two groups on the basis of their resistance to weathering (table 1). A cliff that is resistant to weathering not only lasts longer but also retains longer the attributes that can be exploited by wildlife. Cliffs are further categorized by height, length, joint spacing (cracks or crevices), joint width (table 2), and shape (fig. 2). Combinations of these features provide habitat attributes that can be exploited by wildlife (appendix 1).

Table 1—General resistance of cliffs to weathering

Parent rock	Group I, more resistant	Group II, less resistant
Basalt	X	
Rhyolite	X	
Andesite	X	
Nonwelded tuff		X
Welded tuff	X	
Sedimentary rock (weakly consolidated)		X

Table 2—Structural characteristics of cliffs that produce habitat attributes that can be exploited by adapted species of wildlife

Structural characteristic	Size
Height class	<3 meters (<10 feet) 3-10 meters (10-33 feet) 10-30 meters (33-100 feet) >30 meters (>100 feet)
Length class	<30 meters (<100 feet) 30-100 meters (100-330 feet) 100-500 meters (330-1,640 feet) 500-1 500 meters (1,640-4,920 feet) >1 500 meters (>4,920 feet)
Joint spacing	<0.3 meter (<1 foot) (called netted jointing—fine network of small cracks) 0.3-1.5 meters (1-5 feet) 1.5-7.5 meters (5-25 feet) 7.5-30 meters (25-100 feet) >30 meters (>100 feet)
Joint width (opening size)	<0.15 meter (<0.5 foot) 0.15-0.30 meter (0.5-1 foot) 0.3-0.6 meter (1-2 feet) 0.6-1.5 meters (2-5 feet) >1.5 meters (>5 feet)

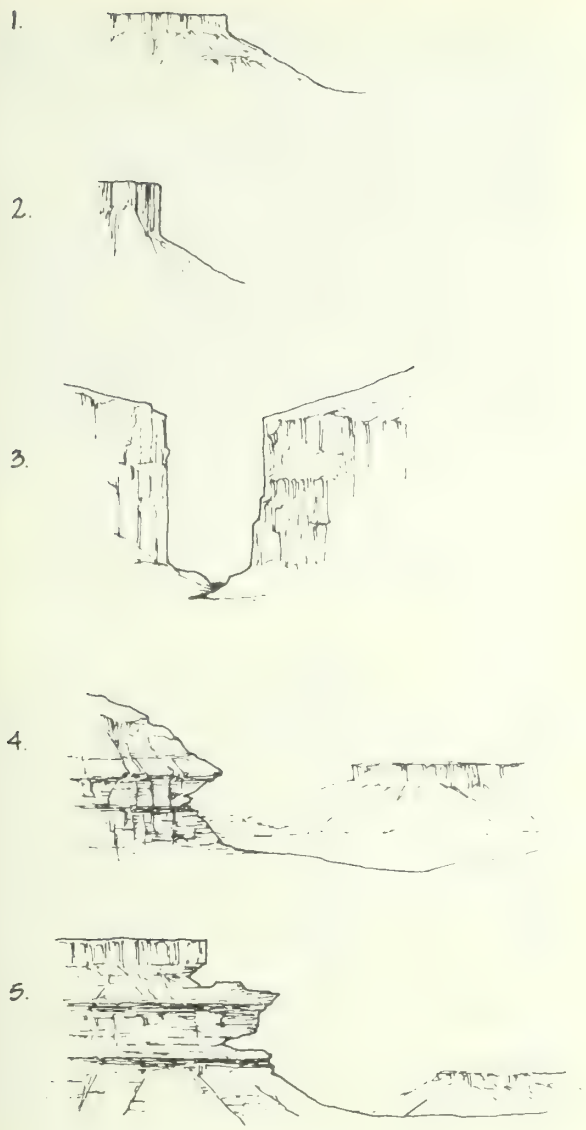


Figure 2.—Shapes of cliffs: (1) cap, (2) scarp, (3) gorge, (4) stratified, (5) combination cap and stratified. (Appendix 1 demonstrates the relationships of wildlife use to these cliff shapes.)

PARENT ROCK

Basalt, andesite, and rhyolite provide the most resistant and prominent cliff features and form shapes 1 through 3 (fig. 2).

These cliffs have structural attributes, such as jointing, that have importance as wildlife habitat. In southeastern Oregon these features are best developed in basalt. When structural features are considered in combination with the availability of the cliff type, basalt remains the most important material, followed by rhyolite and andesite.

Welded tuff parent materials produce scarp- and gorge-shaped formations (shapes 2 and 3 in fig. 2). Joints in welded tuff are rare, but holes or pockets are common and vary from 0.1 to 1 meter (0.3 to 3.3 ft) in diameter. Such cliffs are frequently angular because of inclusions of rock fragments that are resistant to weathering.

Cliffs composed of sedimentary materials often exhibit banding or layering associated with materials that vary in resistance to weathering, forming shelflike and overhanging features that result in cliff shape 4 in figure 2. Sedimentary formations also occur with caps of basalt or andesite to form cliff shape 5 in figure 2.

IMPORTANCE TO WILDLIFE

Cliffs of igneous rock (basalt, andesite, and rhyolite) are more important as wildlife habitat in southeastern Oregon than are those of sedimentary rock because they have the most important long-lived features, such as facial cracks or joints, numerous ledges, and occasional deep caves (fig. 3). Cliffs composed of the readily weatherable sedimentary materials occasionally provide shelflike features and holes or pockets (fig. 4).

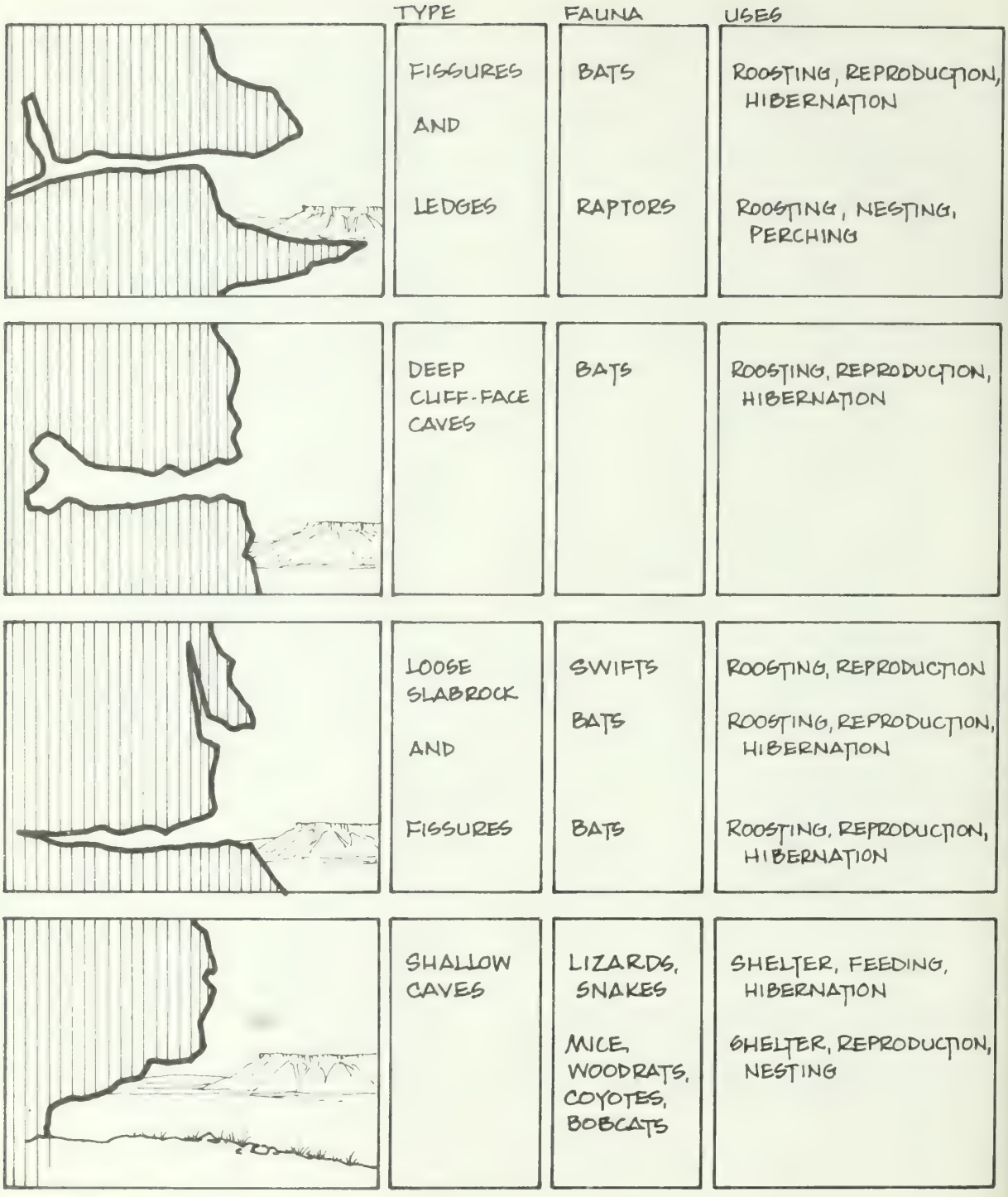


Figure 3.—Features of cliffs and their uses by wildlife.



Figure 4.—Cliffs of easily weathered materials occasionally have shelflike features and holes or pockets (photo courtesy Bureau of Land Management).

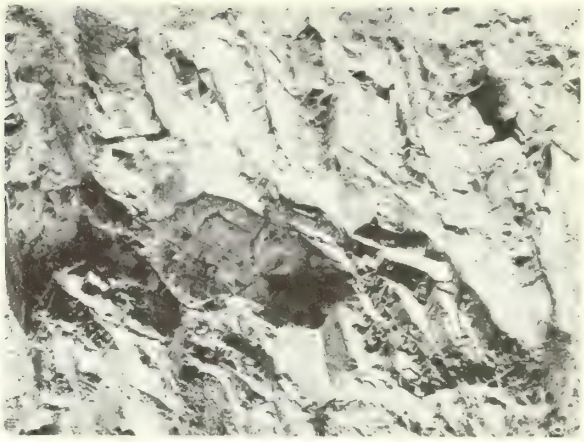


Figure 5.—Cliff swallows use protected areas on cliffs to build their nests and rear their young (photo courtesy Bureau of Land Management).

Cliffs provide secure places for birds to nest and rear young (Bent 1961a, 1961b; Gabrielson and Jewett 1970; Olendorff and Stoddart 1974) (fig. 5). Cliffs also offer shade and some external protection against storms (Fyfe and Olendorff 1976). In addition to physical protection, cliffs produce stable environments within their cracks or joints and caves and thereby buffer environmental extremes.

Most vertebrate animals that use cliffs obtain food and water some distance from those cliffs. A few species feed within or on cliffs. Cliffs next to or within 0.4 kilometer (0.25 mi) of permanent water are far more important for cliff-associated species that require free water (fig. 6).

Most swifts and bats roost and rear their young in cliffs over 12.2 meters (40 ft) in height. The higher a cliff the more habitat it can provide. In addition, the higher a cliff the more predictable the associated thermals or upward-flowing air currents are. These thermals are extensively used by raptors (Craighead and Craighead 1969) and other soaring birds. For example, Denton (1976) found that basaltic cliffs between 7.6 and 30.5 meters (25 and 100 ft) in height were used more that other cliffs by nesting prairie falcons.



Figure 6.—The combination of high cliffs, riparian zones, and a permanent source of water offers excellent wildlife habitat, concentrating a variety of species (photo courtesy Bureau of Land Management).

Cliffs also function as travel routes for some species (fig. 7); they concentrate a variety of reptiles, birds, and mammals into a relatively small, specialized—yet diverse—habitat which, in turn, attracts predators (fig. 8). In fact, cliffs are either essential or disproportionately important to the well-being of a variety of wildlife species (appendix 1).



Figure 7.—An extensive cliff provides habitat for wildlife adapted to cliffs and provides travel routes for some species (photo courtesy Bureau of Land Management).

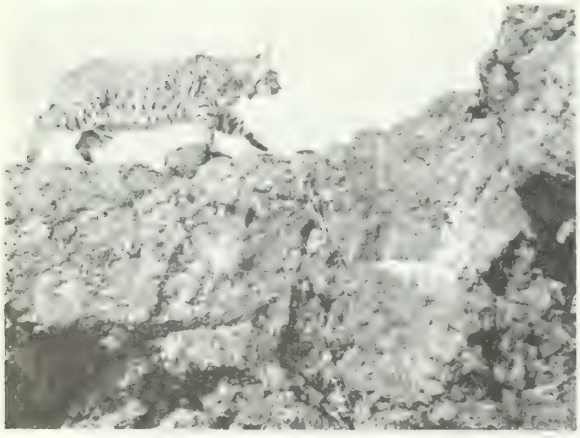


Figure 8.—Bobcats frequently hunt along cliffs where bushy-tailed woodrats are a favored prey. Note the white woodrat urine on the rock in the lower right of the picture (photo courtesy Robert R. Kindschy; used with permission).

It is important, therefore, to know which combinations of cliff attributes best serve as habitat for which species of vertebrate wildlife in a particular area. From the information contained in figure 2 and tables 1 and 2, the cliffs in a specific area can be characterized in a biologically meaningful way. A matrix can match cliff features with their use by wildlife (appendix 1) and reveal a particular cliff's potential as habitat for wildlife.

Caves

Caves are underground chambers that are open to the surface (fig. 9). They may be shallow or deep and are found in igneous or sedimentary rock (fig. 10). Regardless of type or origin, caves are important habitats for some species of wildlife (McDaniel and Gardner 1977, McDaniel and Smith 1976, McReynolds 1976).



Figure 9.—Caves are underground chambers that are open to the surface—in this case a lava tube (photo courtesy of Bureau of Land Management).

PARENT ROCK

Caves in igneous rock, such as basalt, are more important to cave dwellers than are those in sedimentary rock because igneous rock is more resistant to weathering (table 1) and the caves are usually deeper. For example, most deep caves in southeastern Oregon are lava tubes in basalt flows (Ciesiel and Wagner 1969) (figs. 11 and 12).

Caves in more readily weatherable sedimentary materials tend to be shallow and short lived. They are important primarily as nesting and roosting sites for a variety of birds (appendix 1).

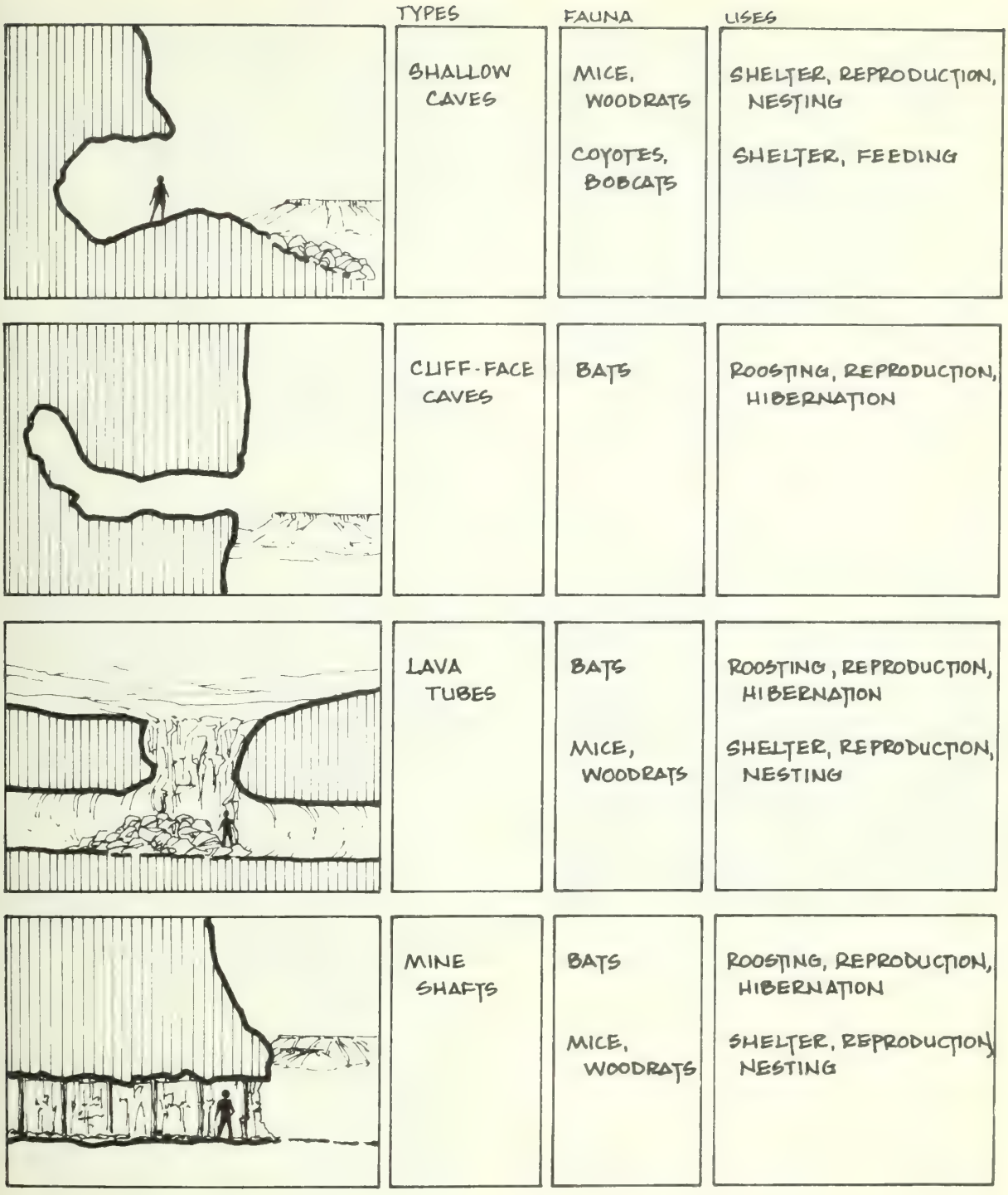


Figure 10.—Types of caves and some of their attendant wildlife.



Figure 11.—Lava tubes are usually discovered when the roof collapses, creating an opening to the surface (photo courtesy Bureau of Land Management).

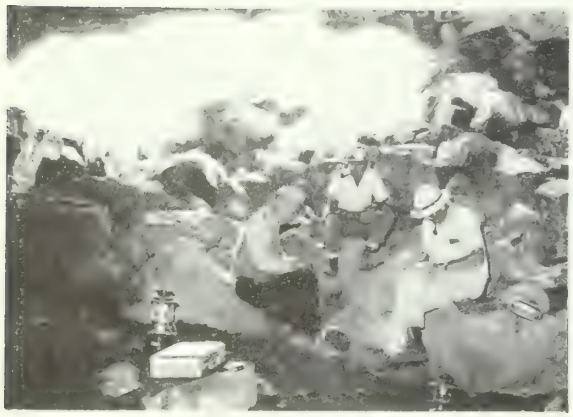


Figure 12.—A collapsed lava tube as seen from inside the tube (photo courtesy Bureau of Land Management).

Caves are divided into two groups based on the resistance of the parent material to weathering (see table 1), and they can be further categorized by diameter and depth (table 3) and degree of darkness. Combinations of these features produce habitat attributes that are exploited by adapted species of wildlife.

Table 3—Structural characteristics of caves that produce habitat attributes which can be exploited by adapted species of wildlife[1]

Structural characteristic	Size class or description
Opening (diameter)	<0.3 meter (<1 foot)
	.03-1 meter (1-3.3 feet)
	>1 meter (>3.3 feet)
Depth of cave (horizontal)	<1 meter (<3.3 feet)
	1-3 meters (3.3-10 feet)
	>3 meters (>10 feet)
Origin	Natural
	Manmade—abandoned mineshaft
	—abandoned railroad tunnel

[1]Appendix 1 illustrates the relationships of wildlife use to these attributes.

IMPORTANCE TO WILDLIFE

Caves offer shelter from weather extremes, physical protection, stable environments, darkness, and seclusion (Barr 1967, Culver 1970, Harris 1970, Poulson and Culver 1969, Poulson and White 1969). For example, the conditions found in deep caves (fig. 13) are essential to some bats (such as the western big-eared bat), which breed, form their nursery colonies, and hibernate in them (Dalquest 1948, Harvey 1976, Mohr 1976, Pearson et al. 1952). Other bats (fig. 14) use caves as night roosts where they periodically hang to digest their food (Barbour and Davis 1969). Caves are also used by a variety of birds and mammals as secure places in which to rear their young, rest, or escape weather extremes.

Deep caves—>3 meters (10 ft)—are scarce in southeastern Oregon; therefore, stable, abandoned mineshafts and railroad tunnels (manmade caves) may provide the same specialized habitats as do natural caves (Barbour and Davis 1969). Shallow caves—<3 meters (10 ft)—on the other hand, are relatively common and are used by a greater variety of wildlife for rearing young, resting, and escaping weather extremes than are deep caves (appendix 1).

From information in tables 1 and 3, caves can be characterized. A matrix comparing cave

features and their use by wildlife (appendix 1) can reveal a particular cave's potential as habitat for wildlife.

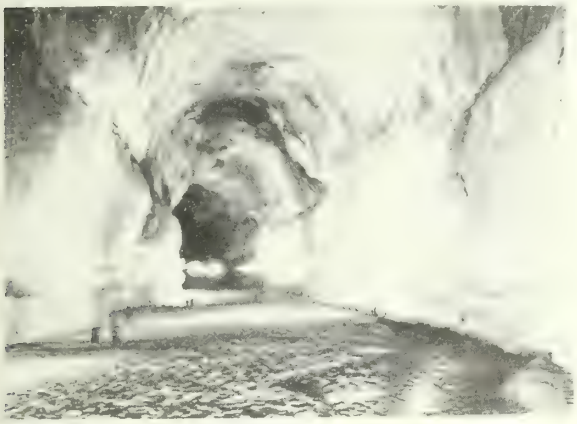


Figure 13.—Deep caves in the northern Great Basin are generally lava tubes formed in basalt (photo courtesy Bureau of Land Management).

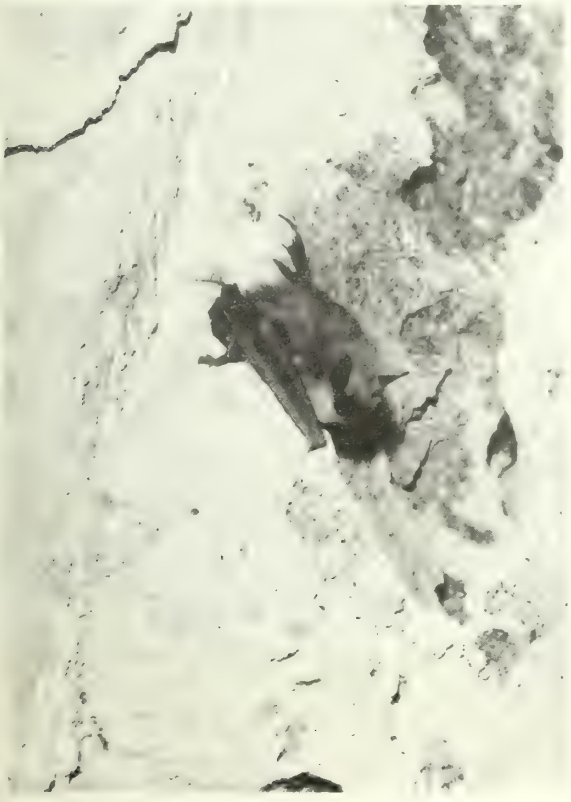


Figure 14.—The small-footed myotis is occasionally found in caves in southeastern Oregon (photo courtesy Robert R. Kindschy; used with permission).

Talus

Talus is the accumulation of rocks on or at the base of steep slopes, usually cliffs (fig. 15). Important structural components of talus include the length, depth, width of the talus deposit, and the type and size classes of rocks (figs. 16 and 17). The length of time a talus has been established and its stability are also important to resident vertebrate wildlife because a well-established, stable talus offers habitat continuity through many generations of the vertebrate species inhabiting it.

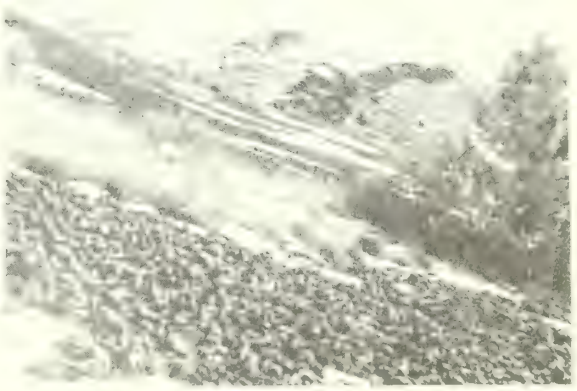


Figure 15.—Talus is an important habitat in the Great Basin (photo courtesy Robert R. Kindschy; used with permission).

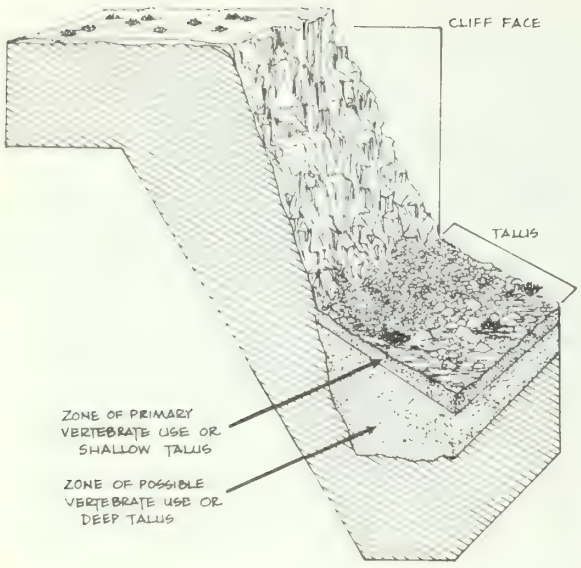


Figure 16.—Talus—the accumulation of rocks that normally occur at the bases of cliffs.

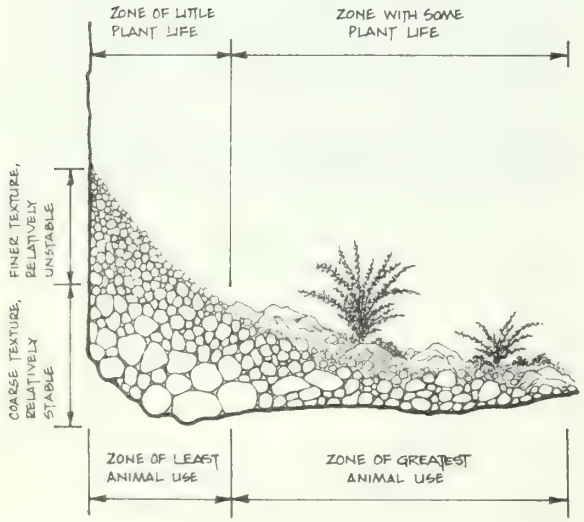


Figure 17.—Anatomy of talus and its use by wildlife.

PARENT ROCK

In general, a large, deep, stable talus field of igneous rock provides better wildlife habitat than does a smaller talus field or talus composed of weakly consolidated sedimentary rock. The latter is not as stable or enduring as the former.

The best talus habitats are generally associated with the toeslopes of cliffs (shapes 1, 2, and 3 in fig. 2). Rocks from these cliffs are mostly large and weather resistant, and resultant talus fields become large, deep, and stable. Talus class (table 4) is important because rock size determines the spaces between rocks which, in turn, determines the size of animals that can inhabit the talus. Rock size also determines which species of vertebrates can use the rocks for sunning or as lookout sites. For example, class II talus may be large enough to serve as lookouts for collared lizards (fig. 18) but is usually too small to serve as lookouts for yellow-bellied marmots.

Table 4—Talus class, based on the predominant or most common rock size in the talus field[1]

Talus class	Rock size (diameter)
I	< 0.5 meter (< 1.6 feet)
II	0.5-1 meter (1.6-3.3 feet)
III	1-2 meters (3.3-6.5 feet)
IV	> 2 meters (> 6.5 feet)

[1]Rock size (talus class) determines the size of the spaces between rocks which, in turn, determine which animals can inhabit those spaces. Appendix 1 illustrates the relationships of wildlife use to talus class.



Figure 18.—Collared lizards are usually associated with class II talus, especially scattered talus on sparsely vegetated hillsides. They use the large rocks as lookouts (photo courtesy Robert R. Kindschy; used with permission).

TALUSLIKE HABITATS

In addition to talus fields, there are taluslike habitats, such as lava stringers, collapsed lava tubes, mine tailings, and roadside "talus."

Lava stringers generally appear as elongated concentrations of rock (fig. 19), possessing a structure similar to talus. Most lava stringers are composed of basalt and are class I talus. Only small wildlife can use these stringers (appendix 1) for rearing young or for hibernation.

Collapsed lava tubes have piles of rock rubble in the area of collapse (fig. 20). Such rubble frequently provides structural features similar to class II talus.

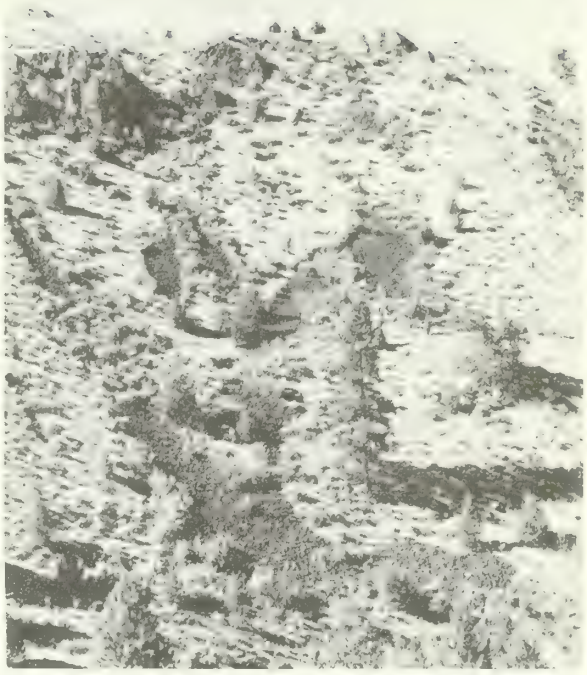


Figure 19.—Lava stringers generally appear as elongated surface concentrations of rock with physical structures similar to talus. Note that the lava stringers have no visible connections to the cliffs. Many, or most, such stringers occur where there are no cliffs.



Figure 20.—Collapsed lava tubes frequently have piles of rock rubble in the collapse area that provide structural features similar to talus (photo courtesy Bureau of Land Management).

Mine tailings, particularly from hard-rock mines, provide taluslike structure. The rock interspaces, however, are often filled with fine materials, limiting their value as wildlife habitat. In addition, early placer mining activity commonly created piles of river rock corresponding to class I talus. Current hard-rock mining activities, on the other hand, produce mine tailings which usually are a mixture of coarse and fine materials corresponding to classes I and II talus. Most of the spaces between the large rocks are filled in by fine materials and are not usable by wildlife.

Roadside "talus" is composed of rock used in construction of roadbeds and can usually be classified in talus class I or II. This can be an important habitat feature because it provides habitat for a variety of vertebrate wildlife in otherwise unsuitable habitat. Such roadside "talus" allows some species to extend their habitats far into otherwise unsuitable areas. It is also possible for roadside "talus" to serve as a connector between natural talus habitats.

IMPORTANCE TO WILDLIFE

Talus provides protection, particularly for reproduction and hibernation, for animals living adjacent to or within it. The environment within a deep talus is more stable and benign than that above it, an important feature during hot summers and cold winters (Krear 1965). Because of its stability, talus is an important geomorphic habitat for ground-dwelling vertebrates, providing diversity over time. Talus also produces an environment that favors an edge of herbaceous vegetation which forms the food supply for vertebrates associated with the talus.

Talus provides a habitat that concentrates lizards, snakes, birds, and mammals; and predators are in turn attracted (appendix 1). From tables 1 and 4, talus can be characterized. Additional descriptors, such as length, depth, and width, of a talus or taluslike formation and its further identification as hillside talus, lava stringer, collapsed lava tube, mine tailing, or roadside talus can provide a meaningful description of a talus. When combined with the data in appendix 1, a talus' potential as wildlife habitat can be predicted.

Lava Flows

There are many old lava flows composed primarily of basalt and andesite (Ciesiel and Wagner 1969, Russell 1903, Walker 1977) which ". . .while molten [were]. . .extruded by volcanoes so as to form sheets which, in many instances, flowed far and wide over the surface of the land before cooling" (Russell 1903, p. 64). McKee (1972, p. 240) asserted that southeastern Oregon "has one of the world's best displays of volcanic landforms." Although most of these lava flows are old (more than 20,000 years, Russell 1903), at least one flow is very young, 4,000 to 9,000 years (Kindschy and Maser 1978, Otto and Hutchison 1977) (figs. 21 and 22).



Figure 21.—Old lava flows (over 20,000 years of age) are fragmented and are covered with varying amounts of soil and vegetation (photo courtesy Robert R. Kindschy; used with permission).



Figure 22.—A recent lava flow (4,000 to 9,000 years old) is often too young for soil or vegetative cover to have developed over its entirety and is, therefore, best suited for habitation of vertebrates around the margin (photo courtesy Robert R. Kindschy; used with permission).

IMPORTANCE TO WILDLIFE

The old flows are fragmented with crevices and are covered with varying amounts of soil and vegetation. The composition and structure of this vegetation commonly differ from the composition and structure of the surrounding rangeland vegetation. Old lava flows create areas of rock rubble of a size similar to talus classes II, III, and IV (table 4). These features combine to form a diversity of habitats caused by the many combinations of talus structure, vegetational structure, and edges of varying contrasts (fig. 21). The mix of habitat attributes associated with old lava flows permits a variety of vertebrate wildlife to concentrate into small areas (appendix 1).

Wildlife may obtain food and both hiding and thermal cover within old lava flows, but in young flows (fig. 22) they normally have to obtain food along the periphery because of the lack of vegetation toward the centers of such flows (appendix 1) (Kindschy and Maser 1978). Lava flows provide crevices of varying depths, as well as shallow caves and lava tubes. These are used by wildlife for rearing young, hibernating, and storing food. In addition, lava flows often protect wildlife habitat from disturbance by cattle which tend to avoid such rocky areas.

Sand Dunes

Sand dunes (fig. 23) in the Great Basin are uncommon and are usually associated with winds' erosion of prehistoric lakebeds (Allison 1966, Baldwin 1976, Butzer 1976, McKee 1972).



Figure 23.—Active sand dunes in the Great Basin are associated with erosion by wind and are limited in distribution (photo courtesy Bureau of Land Management).

IMPORTANCE TO WILDLIFE

Sand dunes, particularly those partially stabilized with vegetation (fig. 24), are important habitat for a variety of vertebrate wildlife (appendix 1).



Figure 24.—Partially stabilized sand dunes are important habitat for both prey and predators, such as the bobcat (photo courtesy Bureau of Land Management).

Although relatively few vertebrates are specifically adapted to sand dunes, some species, such as kangaroo mice and kangaroo rats, are adapted to travel on loose sand but are weak diggers and fare particularly well in sand dunes. These animals easily travel and forage in loose sand and can readily burrow in sand stabilized by vegetation; they exploit food resources along dune edges. They obtain sufficient moisture from their food and do not require free water. In turn, these species are hunted by predators, such as the kit fox (Egoscue 1975, Laughrin 1970, Snow 1973b)—which is listed as threatened in Oregon (Benedict and Forbes 1979, Oregon Department of Fish and Wildlife 1977). Stabilized sand dunes are important, potential hunting grounds for kit foxes (Egoscue 1962).

Playas

Playas are shallow desert basins into which water drains after rainstorms or as snow melts (fig. 25). Playas do not have natural external drainageways, and water is seasonally retained in the basin (Butzer 1976, McKee 1972). Some of the collected water in the playas evaporates and leaves behind once dissolved salts. These salts accumulate as the process is repeated over time.

Because of salts, playas have distinctive plant communities (Bernstein 1962, Brown 1977, Chapman 1960, Magistad 1945, Robinson 1958). Motts (1965) and Neal (1965, 1968a, 1969) have written overview papers on playas.

IMPORTANCE TO WILDLIFE

Playas containing water are important feeding and nesting habitat for some water birds. In addition, during spring and fall migrations, playas containing water are important resting places for waterfowl (appendix 1).

Erosion by wind is common within playas, and the fine materials that are blown out often form into dunes surrounding the deflation plain or basin of a playa (Butzer 1976). Sand dunes and playas frequently occur together, creating more diversity of habitat than where they occur alone.



Figure 25.—A playa basin acts as a catchment. Since a playa has no natural external outlet, the water evaporates and leaves behind the once dissolved salts (photo courtesy Robert R. Kindschy; used with permission).

Edaphic Habitats

Edaphic habitats are specific combinations of soils and vegetation that provide a set of habitat attributes required by certain species of wildlife (fig. 26). Only in circumstances of extreme instability, such as dunes, is vegetation absent. Although edaphic habitats occur virtually everywhere, the edaphic habitat is of special interest in the northern Great Basin because it is the primary habitat of the antelope ground squirrel[2] and is the only habitat for several native endemic plants.[3] [4]

Boundaries between edaphic and other habitats are often sharp. Such boundaries are recognized by changes in vegetative composition, or density, or both. Differences in

[2]Maser, Chris, 1975-77. Unpublished data on file at Puget Sound Museum of Natural History, Univ. Puget Sound, Tacoma, Wash.

[3]Packard, Patricia, 1978. Personal communication. Coll. Idaho, Caldwell.

[4]Soil scientists can help identify the soil which we tentatively classified as a vertic intergrade of a Calcic Argixeroll, shallow, fine loamy, mixed, mesic. It occurs within a more general mapping unit number 60 in a survey of irrigability of southeastern Oregon landscapes (Lovell et al. 1969).



Figure 26.—The light areas in the middle one-third of this photograph exemplify an edaphic habitat of special interest; in southeastern Oregon this is the primary habitat of the antelope ground squirrel (photo courtesy Robert R. Kindschy; used with permission).

species composition and density may be reflected in the structure of the respective plant communities.

The soil has four color phases and is derived from deposits of old lake sediments (lacustrine). Colors of the phases are varied and include the following: light gray (10 YR 7/2), yellowish brown (10 YR 5/8), light olive gray (5 YR 6/2), and reddish brown (2.5 YR 4/4).[5]

The phases are also recognized, when dry, by their soft, loose, almost spongy surfaces which compress 1 to 3 centimeters (0.4-1.2 in) in depressions left by human footprints. The soil surface may be partially covered by flat (platy), coarse, gravel-sized fragments, but most of the surface is composed of smaller, granular particles less than 0.5 millimeter (0.02 in) in diameter. Soil depths are shallow, less than 50 centimeters (20 in). Surface layers are moderately fine textured, and lower layers are higher in clay. A weakly consolidated, though partially fractured, bedrock is usually encountered within 0.3 meter (1 ft) of the surface.

Subsoils shrink and swell markedly during drying and wetting, respectively. During drying, cracks of 2 to 4 centimeters (0.8-1.6 in) appear at the soil surface. These openings speed drying and expose plant roots to severe environmental stress.

The plant community is usually dominated by a meager cover of desert shrubs whose roots extend deep into bedrock fractures. Vegetative structure may be dominated by low, rounded shrubs, such as spiny saltbush (*Atriplex confertifolia*), bud sage (*Artemisia spinescens*), and broom snakeweed (*Gutierrezia sarothrae*); or by tall shrubs, such as big sagebrush (*Artemisia tridentata*), spiny hopsage (*Atriplex spinosa*), or rabbitbrush (*Chrysothamnus* spp.). The associated herbaceous species are easily uprooted from dry, loose soil and tend to be predominantly annuals, mainly cheatgrass (*Bromus tectorum*). Perennial species, such as bottlebrush squirreltail (*Sitanion hystrix*), Sandberg bluegrass (*Poa sandbergii*), bluebunch wheatgrass (*Agropyron spicatum*), buckwheats (*Eriogonum* spp.), and pigweed (*Amaranthus* sp.), may also be present.

IMPORTANCE TO WILDLIFE

Although a few wildlife species may be found on one or more of the phases (appendix 1), the antelope ground squirrel is the only species specifically adapted to this habitat. Adapted primarily to hot deserts of the southwestern United States and Baja California, Mexico, the antelope ground squirrel reaches the northernmost limits of its geographical distribution in the Great Basin of southeastern Oregon, where the edaphic habitat simulates the hot desert.

Appendix 1 shows vertebrates known to be associated with this habitat.

[5]Color names and numerical designations follow those of Munsell Color Company, Inc., Baltimore, Maryland. Use of trade, firm, or corporation names is for the information and convenience of the reader and does not constitute an official endorsement or approval by the U.S. Department of Agriculture or by the U.S. Department of the Interior.

Management Tips

Geomorphic habitats are usually local and occupy a small percentage of the total land base. These habitats cannot be artificially created without great expense or with any assurance that wildlife will use them. They can be destroyed. Manmade "geomorphic" habitats are incidentally used by wildlife when they closely simulate natural habitats. For example, raptors and rock doves may nest in old rock quarries (Kindschy 1964, Murphy et al. 1969); bats may use abandoned mineshafts (Barbour and Davis 1969); and yellow-bellied marmots, ground squirrels, and chipmunks may use roadside talus.

Each geomorphic habitat has at least one animal highly adapted to it for reproduction. Each habitat also concentrates and supports a peculiar animal complex; therefore, plant communities adjacent to these habitats are best maintained as an integral component of the geomorphic habitat since they provide the source of food for the animals (Call 1978).

Removal or alteration of the habitat usually eliminates animals dependent on that habitat. Some animals can be locally extirpated by human disturbance or travel on access roads or trails in the proximity of their habitats. This is most likely when the animals are actively rearing young (Olendorff and Stoddart 1974). If wildlife associated with geomorphic and edaphic habitats are of concern to a manager, access roads and trails, when possible, should be located to avoid unnecessary disturbance to geomorphic or edaphic habitats identified as critical. If an alternate route is not available, travel could be curtailed or kept to a minimum during the reproductive season of the wildlife species of interest.

CLIFFS

Each cliff has attributes that are valuable as habitat for wildlife. For example, vertical cracks or joints, by their size and number, affect the quality and kind of wildlife habitat. Cliffs are vertical, and features cannot be readily described from aerial photographs.

The amount of bushy-tailed woodrat urine visible along a cliff is a good index to general use of a particular cliff by wildlife. Because the bushy-tailed woodrat is usually the largest animal to inhabit the cracks or joints, its presence in numbers usually means that such joints offer ample living space to smaller animals. As a rule, the more woodrat urine visible on a cliff face, the greater the use by wildlife in general.

CAVES

Cave-dwelling bats, such as western big-eared bats, are easily eliminated by human disturbance—cave exploration, artifact hunting, building fires within a cave, and general vandalism (Bailey 1936, Graham 1966). It is therefore advisable not to advertise the location of a cave unless the intent is to develop it specifically for recreational purposes.

Scientific data and resultant management strategies for caves have been developed (see, for example, Aley and Rhodes 1977). Such data can be used to develop management objectives for a specific cave to emphasize either recreation (Tousley 1976) or wildlife (Keith 1977). The wildlife values should be carefully weighed before a decision is made, since deep caves are scarce and development is likely to destroy much or most of a cave's value as habitat for wildlife.

TALUS

There frequently is a temptation to use talus as a ready source of material for roadbeds, but talus concentrates a variety of wildlife species into a small area and provides an important habitat. In fact, talus is critical to the survival of such species as collared lizards over much of their range (Fitch 1956, Storm 1966). Removal of talus destroys the habitat; thus, any anticipated management action should be carefully weighed in the planning process.

Management of mine tailings as wildlife habitat should be done with care because tailings from some mines are toxic to various species of animals (Porter and Hakanson 1976). Such toxicity may limit the utility of tailings as habitat for specific species of wildlife. Cook and Bonham (1977) discussed techniques for sampling vegetation on mine tailings—an equally important consideration in terms of potential management of tailings as wildlife habitat.

LAVA FLOWS

Lava flows are durable and endure most rangeland management activities without visible deleterious effects. But road construction through a lava flow or removal of a portion of a lava flow for use as roadbed material or commercial building materials does alter the wildlife habitat.

SAND DUNES

Sand dunes that are either partially or completely stabilized by vegetation are vulnerable to forces that deteriorate them, particularly livestock and off-road vehicles (Busack and Bury 1974, Sheridan 1978, Snyder et al. 1976). These uses of stabliized dunes destroy the existing vegetation and thereby increase erosion by wind which alters the quality of habitat for wildlife.

If sand dunes are managed as wildlife habitat, the exclusion of other uses should be considered. Some areas, however, could be selected and managed with recreation, such as off-road vehicle use, as the primary objective. In fact, regulations have been formulated for off-road vehicles on public lands (Davey 1974, p. 369):

> No person shall operate an off-road vehicle on public lands: (a) in a reckless, careless, or negligent manner; (b) in excess of established speed limits; (c) while under the influence of alcohol or drugs; (d) in a manner likely to cause excessive damage to or disturbance of the land, wildlife, or vegetative resources. . . .

It seems doubtful that enough forage exists on sand dunes to warrant the risk of increasing their inherent instability through grazing by livestock.

PLAYAS

If playas are to be managed as habitat for wildlife, then the best strategy probably is to protect the playa, its attendant sand dunes, and the adjacent rangelands from the impacts of livestock grazing and off-road vehicle enthusiasts (Bury et al. 1977, Sheridan 1978, Snyder et al. 1976).

Where a shallow playa is a habitual resting place for migratory waterfowl, it may be desirable to deepen a portion of the basin to increase water retention and, thereby, use by waterfowl. This could be done without altering the structure of the entire playa.

EDAPHIC HABITATS

The nature of the edaphic habitat makes it droughty and unstable. As such, it is fragile and particularly vulnerable to grazing by livestock and to off-road vehicular travel (Bury et al. 1977, Sheridan 1978, Snyder et al. 1976). Such activities accelerate erosion by wind and water which makes the habitat less suitable for plant growth and leads to deterioration as habitat for wildlife. Snyder et al. (1976, p. 30) summed it up: "... the effects of off-road vehicle use in arid and semiarid environments are both serious and of long duration."

If protection of habitat for endemic plants and for wildlife is the objective, it should be considered a positive management alternative. This may be most easily accomplished by fencing. Fencing retains maximum flexibility for managing the surrounding rangelands.

A healthy plant community helps retain soil and nutrients that favor stability. Over time, this produces or maintains good habitat for vertebrates associated with edaphic habitats.

Summary

Geomorphic habitats are the products of geologic or geomorphic processes, and edaphic habitats are combinations of vegetation and soils. These habitats "come issued" with the land and cannot, for the most part, be created through land management activities. They provide diversity of habitat in large expanses of otherwise relatively homogeneous landscapes, and this is reflected in increased diversity of wildlife.

Geomorphic and edaphic habitats occupy a small percentage of the total land area in the Great Basin. Some, such as deep caves, sand dunes, playas, and local, distinctive soils, are comparatively rare habitats.

Range management activities involving the alteration or disturbance of geomorphic and edaphic habitats should be carefully evaluated because some wildlife species, such as the threatened kit fox, are highly susceptible to alteration of habitat (Oregon Department of Fish and Wildlife 1977). These habitats should, therefore, be examined by wildlife experts during the planning process to insure their proper management.

Literature Cited

Aldrich, John W.
1939. Geographic variation of the veery. Auk 56(3):338-340.

Aldrich, John W.
1943. Relationships of the Canada jays in the Northwest. Wilson Bull. 55(4):217-222.

Aldrich, John W.
1955. Habits and habitat differences in two races of Traill's flycatcher. Wilson Bull. 65(1):8-11.

Aleksiuk, Michael.
1977. Sources of mortality in concentrated garter snake populations. Can. Field-Nat. 91(1):70-72.

Aley, Tom, and Doug Rhodes, Eds.
1977. National cave management symposium proceedings. 106 p. Speleobooks, Albuquerque, N.M.

Allen, Durward Leon, Ed.
1956. Pheasants in North America. 490 p. Stackpole Co., Harrisburg, Pa., and Wildl. Manage. Inst., Washington, D.C.

Allen, Robert P., and Frederick P. Mangels.
1938-39. Studies of the nesting behavior of the black-crowned night heron. Linnaean Soc. N.Y. Proc. 50, 51:1-28.

Allison, Ira S.
1966. Fossil Lake, Oregon, its geology and fossil faunas. Studies in geology number nine. 48 p. Oreg. State Univ. Press, Corvallis.

American Ornithologists' Union.
1957. Checklist of North American birds. 5th ed. 691 p. Port City Press, Inc., Baltimore, Md.

American Ornithologists' Union.
1973a. Thirty-second supplement to the American Ornithologists' Union checklist of North American birds. Auk 90(2):411-419.

American Ornithologists' Union.
1973b. Corrections and additions to the "Thirty-second supplement to the checklist of North American birds." Auk 90(4):887.

American Ornitholgists' Union.
1976. Thirty-third supplement to the American Ornithologists' Union checklist of North American birds. Auk 93(4):875-879.

Anderson, David R., and Charles J. Henny.
1972. Population ecology of the mallard: I. A review of previous studies and the distribution and migration from breeding areas. U.S. Dep. Inter., Bur. Sport Fish. and Wildl. Resour. Publ. 105, 166 p.

Anderson, David R., Patricia Ann Skaptason, Kathleen G. Fahey, and Charles J. Henny.
1974. Population ecology of the mallard: III. Bibliography of published research and management findings. U.S. Dep. Inter., Bur. Sport Fish. and Wildl. Resour. Publ. 119, 46 p.

Anderson, James D.
1967. A comparison of the life histories of coastal and montane populations of *Ambystoma macrodactylum* in California. Am. Midl. Nat. 77(2):323-355.

Anderson, James D.
1968. A comparison of the food habits of *Ambystoma macrodactylum sigillatum, Ambystoma macrodactylum croceum*, and *Ambystoma tigrinum californiense*. Herpetologica 24(4):273-284.

Anderson, John R., and Richard W. Merrill.
1967. The impact of foraging meadowlarks (*Sturnus neglecta*) on the degradation of cattle dung pads. J. Appl. Ecol. 14(2):355-362.

Anderson, John Robert.
1976. Relation of the northern pocket gopher to forest habitats in south-central Oregon. M.S. thesis. Oreg. State Univ., Corvallis. 46 p.

Anderson, Stanley H.
1972. Seasonal variations in forest birds of western Oregon. Northwest Sci. 46(3):194-206.

Anderson, Stanley H.
1976. Comparative food habits of Oregon nuthatches. Northwest Sci. 50(4):213-221.

Anderson, T. R.
1973. A comparative study of the house sparrow and the tree sparrow near Portage des Sioux, Missouri. Ph. D. thesis. St. Louis Univ., St. Louis, Mo. 157 p.

Anthony, Robert.
1970. Ecology and reproduction of California quail in southeastern Washington. Condor 72(3):276-287.

Apfelbaum, Steven, and Alan Haney.
1977. Nesting and foraging activity of the brown creeper in northeastern Minnesota. Loon 49(2):78-80.

Apslund, Kenneth K.
1974. Body size and habitat utilization in whiptail lizards (*Cnemidophorus*). Copeia 1974(3):695-703.

Armitage, K. B.
1975. Social behavior and population dynamics of marmots. Oikos 26:341-354.

Armitage, Kenneth B., and Jerry F. Downhower.
1974. Demography of yellow-bellied marmot populations. Ecology 55(6):1233-1245.

Armstrong, E. A.
1956. Territory in the wren, *Troglodytes troglodytes*. Ibis 98(3):430-437.

Armstrong, F. H.
1957. Notes on *Sorex preblei* in Washington State. Murrelet 38(1):6.

Armstrong, Joseph T.
1965. Breeding home range in the nighthawk and other birds; its evolutionary and ecological significance. Ecology 46(5):619-629.

Ashmole, N. Philip.
1968. Competition and interspecific territoriality in *Empidonax* flycatchers. Syst. Zool. 17(2):210-212.

Autenrieth, Robert E., and Edson Fichter.
1975. On the behavior and socialization of pronghorn fawns. Wildl. Monogr. 42, 111 p.

Bailey, Theodore N.
1971. Biology of striped skunks on a southwestern Lake Erie marsh. Am. Midl. Nat. 85(1):196-201.

Bailey, Vernon.
1936. The mammals and life zones of Oregon. North Am. Fauna 55, 416 p. USDA Bur. Biol. Surv., Washington, D.C.

Baker, Rollin H., and Mary W. Baker.
1975. Montane habitat used by the spotted skunk (*Spilogale putorius*) in Mexico. J. Mammal. 56(3):671-673.

Bakke, Eric L.
1977. Bohemian waxwing populations and winter ecology in North Dakota. Prairie Nat. 9(3 & 4):43-46.

Balda, Russell P., and Gary C. Bateman.
1971. Flocking and annual cycle of the piñon jay, *Gymnorhinus cyanocephalus*. Condor 73(3):287-302.

Balda, Russell P., Barbara Clark McKnight, and Clarence D. Johnson.
1975. Flammulated owl migration in the southwestern United States. Wilson Bull. 87(4):520-533.

Baldwin, Ewart M.
1976. Geology of Oregon. (Rev.) 147 p. Kendall/Hunt Publ. Co., Dubuque, Iowa.

Baldwin, Paul H., and William F. Hunter.
1963. Nesting and nest visitors of the Vaux's swift in Montana. Auk 80(1):81-85.

Baldwin, Paul H., and Nick K. Zaczkowski.
1963. Breeding biology of the Vaux swift. Condor 65(5):400-406.

Balph, Martha Hatch.
1976. Golden-crowned sparrows in northern Utah. North Am. Bird Bander 1(2):67.

Balph, Martha Hatch.
1977. Winter social behavior of dark-eyed juncos; communication, social organization, and ecological implications. Anim. Behav. 25(4):859-884.

Balph, Martha Hatch.
1978. Some population trends among Cassin's finch in northern Utah. North Am. Bird Bander 3(1):12-15.

Balph, Martha Hatch, and David F. Balph.
1976. Some factors influencing observed sex ratios in a population of evening grosbeaks. Bird Banding 47(4):340-344.

Banfield, A. W. F.
1947. A study of the winter feeding habits of the short-eared owl (*Asio flammeus*) in the Toronto region. Can. J. Res. Sect. D. 25(2):45-65.

Banks, Richard C.
1970. The fox sparrow on the west slope of the Oregon Cascades. Condor 72(3):369-370.

Barbour, Roger William, and Wayne H. Davis.
1969. Bats of America. 286 p. Univ. Press Ky., Lexington.

Barr, T. C., Jr.
1967. Observations on the ecology of caves. Am. Nat. 101(922):475-491.

Barry, Thomas W.
1964. Brant, Ross' goose and emperor goose. *In* Waterfowl tomorrow, p. 145-154. J. P. Linduska, ed. U.S. Dep. Inter., Bur. Sport Fish. and Wildl., Washington, D.C.

Bartonek, J. C., and J. J. Hickey.
1969. Food habits of canvasbacks, redheads, and lesser scaup in Manitoba. Condor 71(3):280-290.

Bateman, Gary C., and Russell P. Balda.
1973. Growth, development, and food habits of young pinyon jays. Auk 90(1):39-61.

Baumann, S. A.
1959. The breeding cycle of the rufous-sided towhee, *P. erythrophthalmus* (L.) in central California. Wasmann J. Biol. 17:161-220.

Baumgartner, Frederick M.
1939. Territory and population in the great horned owl. Auk 56(3):274-282.

Bear, G. D., and R. M. Hansen.
1966. Food habits, growth and reproduction of white-tailed jackrabbits in southern Colorado. Agric. Exp. Stn. Tech. Bull. 90, 59 p. Colo. State Univ., Fort Collins.

Beason, Robert C., and Edwin C. Franks.
1974. Breeding behavior of the horned lark. Auk 91(1):65-74.

Beatley, Janice C.
1976. Environment of kangaroo rats (*Dipodomys*) and effects of environmental change on populations in southern Nevada. J. Mammal. 57(1):67-93.

Beaver, Donald L., and Paul H. Baldwin.
1975. Ecological overlap and the problem of competition and sympatry in the western and Hammond's flycatchers. Condor 77(1):1-13.

Beck, Albert J., and Robert L. Rudd.
1960. Nursery colonies in the pallid bat. J. Mammal. 41(2):266-267.

Beck, Lee R., and Robert G. Anthony.
1971. Metabolic and behavioral thermoregulation in the long-tailed vole, *Microtus longicaudus*. J. Mammal. 52(2):404-412.

Beecham, John J., and M. N. Kochert.
1975. Breeding biology of the golden eagle in southwestern Idaho. Wilson Bull. 87(4):506-513.

Bendell, J. F., and P. W. Elliott.
1967. Behaviour and the regulation of numbers in blue grouse. Can. Wildl. Serv. Rep. Ser. 4, 76 p. Ottawa.

Benedict, Ellen M., and Richard B. Forbes.
1979. Kit fox skulls in a southeastern Oregon cave. Murrelet 60(1):25-27.

Bennett, James W., and Eric G. Bolen.
1978. Stress response in wintering green-winged teal. J. Wildl. Manage. 42(1):81-86.

Bent, Arthur Cleveland.
1926. Life histories of North American marsh birds: Orders *Odontoglossae, Herodiones,* and *Paludicolae*. Smithson. Inst. U.S. Nat. Mus. Bull. 135, 490 p.

Bent, Arthur Cleveland.
1961a. Life histories of North American birds of prey. Part 1. 409 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1961b. Life histories of North American birds of prey. Part 2. 482 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1962a. Life histories of North American wildfowl. Part 1. 224 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1962b. Life histories of North American wildfowl. Part 2. 314 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1962c. Life histories of North American shore birds. Part 2. 340 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1962d. Life histories of North American shore birds. Part 1. 359 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1963a. Life histories of North American diving birds. 239 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1963b. Life histories of North American gulls and terns. 337 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1963c. Life histories of North American flycatchers, larks, swallows, and their allies. 555 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1963d. Life histories of North American wood warblers. Part 1. p. 1-367. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1963e. Life histories of North American wood warblers. Part 2. p. 367-734. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1964a. Life histories of North American petrels and pelicans and their allies. 335 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1964b. Life histories of North American cuckoos, goatsuckers, hummingbirds and their allies. Part 2. 261 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1964c. Life histories of North American woodpeckers. 334 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1964d. Life histories of North American jays, crows, and titmice. Part 1. 214 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1964e. Life histories of North American jays, crows and titmice. Part 2. 280 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1964f. Life histories of North American nuthatches, wrens, thrashers and their allies. 475 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1964g. Life histories of North American thrushes, kinglets, and their allies. 452 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1965a. Life histories of North American wagtails, shrikes, vireos, and their allies. 411 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1965b. Life histories of North American blackbirds, orioles, tanagers, and their allies. 549 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1968a. Life histories of North American cardinals, grosbeaks, buntings, towhees, finches, sparrows, and allies, Order Passeriformes: Family Fringillidae. Part 1. 602 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1968b. Life histories of North American cardinals, grosbeaks, buntings, towhees, finches, sparrows, and allies, Order Passeriformes: Family Fringillidae. Part 2. 646 p. Dover Publ. Inc., New York.

Bent, Arthur Cleveland.
1968c. Life histories of North American cardinals, grosbeaks, buntings, towhees, finches, sparrows, and allies, Order Passeriformes: Family Fringillidae. Part 3. 640 p. Dover Publ., Inc., New York.

Berger, Joel.
1978. Maternal defensive behavior in bighorn sheep. J. Mammal. 59(3):620-621.

Bernstein, Leon.
1962. Salt-affected soils and plants. Probl. Arid Zone, Proc. Paris Symp., Paris, UNESCO, p. 139-175 (Arid Zone Res. 18).

Bertin, Robert I.
1977. Breeding habitats of the wood thrush and veery. Condor 79:303-311.

Bertrand, Gerard A., and J. Michael Scott.
1973. Checklist of the birds of Oregon. 17 p. Mus. Nat. Hist., Oreg. State Univ. Dep. Zool., Corvallis.

Best, Louis B.
1972. First-year effects of sagebrush control on two sparrows. J. Wildl. Manage. 36(2):534-544.

Bicak, Thomas K.
1977. Some eco-ethological aspects of a breeding population of long-billed curlews (*Numenius americanus*) in Nebraska. Proc. Nebr. Acad. Sci. and Affil. Soc. 87:7.

Billard, Ruth S.
1947. An ecological study of the Virginia rail (*Rallus limicola limicola*) and the sora (*Porzana carolina*) in some Connecticut swamps. M.S. thesis. Iowa State Univ., Ames. 84 p.

Birkenholz, Dale E.
1967. The harvest mouse (*Reithrodontomys megalotis*) in central Illinois. Trans. Ill. State Acad. Sci. 60(1):49-53.

Blackburn, Delfoy.
1968. Behavior of while-tailed and black-tailed jackrabbits of mid-eastern Oregon. M.S. thesis. Univ. Idaho, Moscow. 47 p.

Blair, W. Frank.
1943. Populations of the deer mouse and associated small mammals in the mesquite association of southern New Mexico. Contrib. Lab. Vert. Biol. 21, 40 p. Univ. Mich.

Blais, J. R., and G. H. Parks.
1964. Interaction of evening grosbeak (*Hesperiphona vespertina*) and spruce budworm (*Choristoneura fumiferana* (Clem)) in a localized budworm outbreak treated with DDT in Quebec. Can. J. Zool. 42(6):1017-1024.

Blaker, D.
1969. Behavior of the cattle egret, *Ardeola ibis*. Ostrich 40:75-129.

Blaustein, Andrew R., and Arthur C. Risser, Jr.
1976. Interspecific interactions between three sympatric species of kangaroo rats (*Dipodomys*). Anim. Behav. 24(2):381-385.

Bleich, Vernon C., and Orlando A. Schwartz.
1975. Observations on the home range of the desert woodrat, *Neotoma lepida intermedia*. J. Mammal. 56(2):518-519.

Bock, Carl E.
1970. The ecology and behavior of the Lewis woodpecker. Univ. Calif. Publ. Zool. 92, 100 p.

Bock, Carl E., Harlo H. Hadow, and Preston Somers.
1971. Relations between Lewis' and red-headed woodpeckers in southeastern Colorado. Wilson Bull. 83(3):237-248.

Bock, Carl E., and Larry W. Lepthien.
1975. Distribution and abundance of the black-billed magpie (*Pica pica*) in North America. Great Basin Nat. 35(3):269-272.

Bogert, C. M., and V. D. Roth.
1966. Ritualistic combat of male gopher snakes, *Pituophis melanoleucus affinis* (Reptilia, Colubridae). Am. Mus. Novit. 2245:1-27.

Bradley, Richard A.
1973. A population census of the Belding's savannah sparrow, *Passerculus sandwichensis beldingi*. West. Bird Bander 48:40-43.

Bradley, W. Glen.
1967. Home range, activity patterns, and ecology of the antelope ground squirrel in southern Nevada. Southwest. Nat. 12(3):231-252.

Bradley, W. Glen.
1968. Food habits of the antelope ground squirrel in southern Nevada. J. Mammal. 49(1):14-21.

Bragg, Arthur N.
1940. Observations on the natural history of Anura. II. Habits habitat, and breeding of *Bufo woodhouseii woodhouseii* (Girard) in Oklahoma. Am. Midl. Nat. 24:306-321.

Bragg, Arthur N.
1945. The spadefoot toads in Oklahoma with a summary of our knowledge of the group. II. Am. Nat. 79(780):52-72.

Braun, Clait E., Maurice F. Baker, Robert L. Eng, Jay S. Gashwiler, and Max M. Schroeder.
1976. Conservation committee report on effects of alteration of sagebrush communities on the associated avifauna. Wilson Bull. 88(1):165-171.

Braun, Clait E., Tim Britt, and Richard O. Wallestad.
1977. Guidelines for maintenance of sage grouse habitats. Wildl. Soc. Bull. 5(3):99-106.

Bray, Olin E., Kenneth H. Larsen, and Donald F. Mott.
1975. Winter movements and activities of radio-equipped starlings. J. Wildl. Manage. 39(4):795-801.

Broadbooks, Harold E.
1958. Life history and ecology of the chipmunk *Eutamias amoenus*, in eastern Washington. Univ. Mich. Misc. Publ. 103, 49 p. Mus. Zool., Ann Arbor.

Broadbooks, Harold E.
1961. Ring-billed gulls nesting on Columbia River islands. Murrelet 42(1):7-8.

Broadbooks, Harold E.
1970a. Home ranges and territorial behavior of the yellow-pine chipmunk, *Eutamias amoenus*. J. Mammal. 51(2):310-326.

Broadbooks, Harold E.
1970b. Populations of the yellow-pine chipmunk, *Eutamias amoenus*. Am. Midl. Nat. 83(2):472-488.

Brodkorb, Pierce.
1949. Variation in the North American forms of western flycatcher. Condor 51(1):35-39.

Brown, Herbert A.
1975. Embryonic temperature adaptations of the Pacific treefrog, *Hyla regilia*. Comp. Biochem. Physiol. 51(4A):863-873.

Brown, J. L.
1963. Aggressiveness, dominance, and social organization in the Steller jay. Condor 65:460-484.

Brown, Larry N.
1967. Seasonal activity patterns and breeding of the western jumping mouse (*Zapus princeps*) in Wyoming. Am. Midl. Nat. 78(2):460-470.

Brown, Leslie, and Dean Amadon.
1968. Eagles, hawks, and falcons of the world. Vols. 1 and 2. 945 p. McGraw-Hill Book Co., New York.

Brown, Randall E.
1977. Greasewood in ancient playa lake deposits in the Pasco Basin, and geologic causes of its presence. *In* Proceedings of the symposium on terrestrial and aquatic ecological studies of the northwest, p. 39-45. Rollin D. Andrews III, Robert L. Carr, Flash Gibson, and others, eds. East. Wash. State Coll. Press, Cheney.

Brown, Robert Lee.
1957. The population ecology of the magpie in western Montana. M.S. thesis. Univ. Mont., Missoula. 60 p.

Brown, William S., and Williams S. Parker.
1976. Movement ecology of *Coluber constrictor* near communal hibernacula. Copeia 1976(2):225-242.

Brown, Woodward H.
1973. Winter population trends in the marsh, Cooper's, and sharp-shinned hawks. Am. Birds 27(1):6-7.

Bucher, John E.
1978. On sexing American avocets and long-billed curlews. Inland Bird Banding News 50(1):15-18.

Buchler, Edward R.
1976. Prey selection by *Myotis lucifugus*. Am. Nat. 110(974):619-628.

Bump, Gardiner, Robert W. Darrow, Frank C. Edminster, and Walter F. Crissey.
1947. The ruffed grouse: Life history, propagation, management. 915 p. N. Y. State Conserv. Dep., Albany.

Bunni, Munir Kiriacose.
1959. The killdeer, *Charadrius vociferus* (Linn.), in the breeding season: Ecology, behavior, and the development of homoiothermism. Sc.D. thesis Univ. Mich., Ann Arbor. 366 p.

Burger, Joanna.
1974. Breeding adaptations of Franklin's gull (*Larus pipixcan*) to a marsh habitat. Anim. Behav. 22(3):521-567.

Burger, Joanna.
1978. Competition between cattle egrets and native North American herons, egrets, and ibises. Condor 80(1):15-23.

Burger, Joanna, and Marshall Howe.
1975. Notes on winter feeding behavior and molt in Wilson's phalaropes. Auk 92(3):442-451.

Burger, Joanna, and Lynne M. Miller.
1977. Colony and nest site selection in white-faced and glossy ibises. Auk 94(4):664-676.

Burkholder, Gary L., and J. M. Walker.
1973. Habitat and reproduction of the desert whiptail lizard, *Cnemidophorus tigris* Baird and Girard, in southwestern Idaho at the northern part of its range. Herpetologica 29(1):76-83.

Burleigh, Thomas D.
1963. Geographic variation in the cedar waxwing (*Bombycilla cedrorum*). Biol. Soc. Wash. Proc. 76:177-180.

Burt, William Henry, and Richard Philip Grossenheider.
1964. A field guide to the mammals: Field marks of all species found north of the Mexican boundary. 2d ed. 284 p. Houghton Mifflin, Boston.

Burton, John A., Ed.
1973. Owls of the world: Their evolution, structure, and ecology. 216 p. Dutton, New York.

Bury, R. Bruce, Roger A. Luckenbach, and Stephen D. Busack.
1977. Effects of off-road vehicles on vertebrates in the California desert. U.S. Dep. Inter., Fish and Wildl. Serv., Wildl. Res. Rep. 8, 23 p. Washington, D.C.

Busack, Stephen D., and R. Bruce Bury.
1974. Some effects of off-road vehicles and sheep grazing on lizard populations in the Mojave Desert. Biol. Conserv. 6(3):179-183.

Buss, Iwen O.
1942. A managed cliff swallow colony in southern Wisconsin. Wilson Bull. 54(3):153-161.

Butzer, Karl W.
1976. Geomorphology from the earth. 463 p. Harper and Row Publ., New York.

Cade, Tom J.
1962. Wing movements, hunting, and displays of the northern shrike. Wilson Bull. 74(2):386-408.

Cade, Tom J.
1967. Ecological and behavioral aspects of predation by the northern shrike. Living Bird 6:43-86.

Calder, William A.
1971. Temperature relationships and nesting of the calliope hummingbird. Condor 73(3):314-321.

Calder, William A.
1973. Microhabitat selection during nesting of hummingbirds in the Rocky Mountains. Ecology 54(1):127-134.

Calder, William A., and Joanna Booser.
1973. Hypothermia of broad-tailed hummingbirds during incubation in nature with ecological correlations. Science 180(4087):751-753.

Call, Mayo W.
1978. Nesting habitats and surveying techniques for common western raptors. U.S. Dep. Inter., Bur. Land Manage. Tech. Note 316, 115 p. Denver, Colo.

Campbell, James B.
1970. Life history of *Bufo boreas boreas* in the Colorado Front Range. Ph. D. thesis. Univ. Colo., Boulder. 124 p.

Carpenter, Charles C.
1952. Comparative ecology of the common garter snake (*Thamnophis s. sirtalis*), the ribbon snake (*Thamnophis s. sauritus*), and Butler's garter snake (*Thamnophis butleri*) in mixed populations. Ecol. Monogr. 22(4):235-258.

Chapin, E. A.
1925. Food habits of the vireos: A family of insectivorous birds. U.S. Dep. Agric. Bull. 1355. 44 p.

Chapman, Joseph A.
1975. *Sylvilagus nuttallii.* Am. Soc. Mammal., Mammal. Species 56, p. 1-3.

Chapman, Lawrence B.
1935. Studies of a tree swallow colony. Bird Banding 6(2):45-57.
Chapman, V. J.
1960. Salt marshes and salt deserts of the world. 392 p. Interscience Publ., Inc., New York.
Christian, John J.
1956. The natural history of a summer aggregation of the big brown bat, *Eptesicus fuscus fuscus*. Am. Midl. Nat. 55(1):66-95.
Ciesiel, Robert F., and Norman S. Wagner.
1969. Lava-tube caves in the Saddle Butte area of Malheur County, Oregon. Ore Bin 31(8):153-171.
Clanton, C. Wesley, Marion Bacon, and W. R. Giedt.
1971. Campestral plague in central Washington with particular observations of plague in the sagebrush vole. 74 p. Dep. Soc. and Health Serv., Health Serv. Div. Public Health Lab. [Wash. Dep. Health], Seattle.
Clark, Donald R., Jr., and Carl S. Lieb.
1973. Notes on reproduction of the night snake (*Hypsiglena torquata*). Southwest. Nat. 18(2):248-255.
Clark, Richard J.
1975. A field study of the short-eared owl, *Asio flammeus* (Pontoppidan), in North America. Wildl. Monogr. 47, 67 p. Wildl. Soc., Washington, D.C.
Clark, Richard J., and James G. Ward.
1974. Interspecific competition in two species of open country raptors *Circus cyaneus* and *Asio flammeus*. Pa. Acad. Sci. Proc. 48:79-87.
Clark, William H., and Peter L. Comanor.
1976. The northern desert horned lizard, *Phrynosoma platyrhinos platyrhinos*, as a predator of the western harvester ant, *Pogonomyrmex occidentalis*, and a dispersal agent for *Eriogonum baileyi*. J. Idaho Acad. Sci. 12(1):9-12.
Clarke, Raymond D.
1974a. Food habits of toads, genus *Bufo* (Amphibia: Bufonidae). Am. Midl. Nat. 91(1):140-147.
Clarke, Raymond D.
1974b. Activity and movement patterns in a population of Fowler's toad, *Bufo woodhousei fowleri*. Am. Midl. Nat. 92(2):257-274.
Clothier, Ronald R.
1955. Contribution to the life history of *Sorex vagrans* in Montana. J. Mammal. 36(2):214-221.
Cochran, W. W., G. G. Montgomery, and R. R. Graber.
1967. Migratory flights of *Hylocichal* thrushes in spring: A radio-telemetry study. Living Bird 6:213-225.
Cole, Leon J.
1943. Behavior of northern phalarope with young. Condor 45(1):39.
Coles, Victor.
1938. Studies in the life history of the turkey vulture, *Cathartes aura septentrionalis* (Wied). Ph. D. thesis. Cornell Univ., Ithaca, N.Y. 632 p.
Collins, Charles T., and Ross E. Landry.
1977. Artificial nest burrows for burrowing owls. North Am. Bird Bander 2(4):151-154.
Combellack, C. R. B.
1954. A nesting of violet-green swallows. Auk 71(4):435-442.
Connelly, John W., Jr.
1978. Trends in blue-winged and cinnamon teal population of eastern Washington. Murrelet 59(1):2-6.
Conner, Richard N., Robert G. Hooper, Hewlette S. Crawford, and Henry S. Mosby.
1975. Woodpecker nesting habitat in cut and uncut woodlands in Virginia. J. Wildl. Manage. 39(1):144-150.
Conner, Richard N., Orson K. Miller, Jr., and Curtis S. Adkisson.
1976. Woodpecker dependence on trees infected by fungal heart rots. Wilson Bull. 88(4):575-581.
Conner, Richard Neil.
1973. Woodpecker utilization of cut and uncut woodlands. M.S. thesis. Va. Polytech. Inst. and State Univ., Blacksburg. 82 p.
Constantine, Denny G.
1966. Ecological observations on Lasiurine bats in Iowa. J. Mammal. 47(1):34-41.
Cooch, Frederick Graham.
1958. The breeding biology and management of the blue goose (*Chen caerulescens*). Ph. D. thesis. Cornell Univ., Ithaca, N.Y. 246 p.

Cook, C. Wayne, and Charles D. Bonham.
1977. Techniques for vegetation measurements and analysis for a pre- and post- mining inventory. Range Sci. Ser. 28, 93 p. Dep. Range Sci., Colo. State Univ., Fort Collins.

Cooper, James A.
1978. The history and breeding biology of the Canada geese of Marshy Point, Manitoba. Wildl. Monogr. 61, 87 p.

Cortopassi, A. J., and L. R. Mewaldt.
1965. The circumannual distribution of white-crowned sparrows. Bird Banding 36:141-169.

Crabb, Wilfred D.
1948. The ecology and management of the prairie spotted skunk in Iowa. Ecol. Monogr. 18(2):201-232.

Craig, Robert B.
1978. An analysis of the predatory behavior of the loggerhead shrike. Auk 95(2):221-234.

Craighead, John Johnson, and Frank C. Craighead, Jr.
1969. Hawks, owls, and wildlife. 443 p. Dover Publ., Inc., New York. [Originally published in 1956 by Stackpole Co., Harrisburg, Pa.]

Cranford, Jack A.
1978. Hibernation in the western jumping mouse, *Zapus princeps*. J. Mammal. 59(3):496-509.

Crase, Frederick T., and Richard W. DeHaven.
1975. Selected bibliography on the food habits of North American blackbirds. U.S. Dep. Inter., Fish and Wildl. Serv. Spec. Sci. Rep. Wildl. 192, 20 p.

Crawford, Richard D.
1977. Comparison of trapping methods for American coots. Bird Banding 48(4):309-313.

Crockett, Allen B., and Paula L. Hansley.
1977. Coition, nesting, and post-fledging behavior of Williamson's sapsucker in Colorado. Living Bird 16:7-19.

Cross, Stephen P.
1965. Roosting habits of *Pipistrellus hesperus*. J. Mammal. 46(2):270-279.

Cross, Stephen P.
1977. A survey of the bats of Oregon Caves National Monument. 40 p. Natl. Park Serv.

Crouse, Carl N.
1941. The value of small reserves in pheasant management in Whitman County, Washington. M.S. thesis. Wash. State Coll., Pullman. 36 p.

Crowe, Douglas M.
1975. A model for exploited bobcat populations in Wyoming. J. Wildl. Manage. 39(2):408-415.

Culver, David C.
1970. Analysis of simple cave communities. I. Caves as islands. Evolution 24(2):463-474.

Curry-Lindahl, K.
1971. Systematic relationships in herons (Ardeidae) based on comparative studies of behavior and ecology: A preliminary account. Ostrich Suppl. 9:53-70.

Cutright, Noel J.
1973. A bibliography on the red-winged blackbird. 24 p. Dep. Nat. Resour., Cornell Univ., Ithaca, N.Y.

Dalquest, Walter W.
1947a. Notes on the natural history of the bat, *Myotis yumanensis*, in California, with a description of a new race. Am. Midl. Nat. 38(1):224-247.

Dalquest, Walter W.
1947b. Notes on the natural history of the bat *Corynorhinus rafinesquii* in California. J. Mammal. 28(1):17-30.

Dalquest, Walter W.
1948. Mammals of Washington. Kans. Univ. Mus. Nat. Hist. Publ. 2:1-444.

Darham, Leonard, and George W. Bennett.
1963. Age, growth, and homing in the bullfrog. J. Wildl. Manage. 27(1):107-123.

Davey, Stuart P.
1974. Off-road vehicles on or off the public lands. Trans. North Am. Wildl. Nat. Resour. Conf. 39:367-375.

Davis, David E.
1954. The breeding biology of Hammond's flycatcher. Auk 71(2):164-171.

Davis, David E.
1974. Emigrations of northern shrikes 1959-1970. Auk 91(4):821-825.

Davis, John.
1960. Nesting behavior of the rufous-sided towhee in coastal California. Condor 62(6):434-456.

Davis, John, George F. Fisler, and Betty S. Davis.
1963. The breeding biology of the western flycatcher. Condor 65(5):337-382.

Davis, John, and Nicholas A. M. Verbeek.
1972. Habitat preferences and the distribution of *Uta stanisburiana* and *Sceloporus occidentalis* in coastal California. Copeia 1972(4):643-649.

Davis, Russell.
1969. Growth and development of young pallid bats, *Antrozous pallidus*. J. Mammal. 50(4):729-736.

Davis, Wayne H., Roger W. Barbour, and Marion D. Hassell.
1968. Colonial behavior of *Eptesicus fuscus*. J. Mammal. 49(1):44-50.

Dealy, J. Edward.
1970. Survival and growth of bitterbrush on the Silver Lake deer winter range in central Oregon. USDA For. Serv. Res. Note PNW-133, 5 p., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

DeHaven, Richard W., and Phyllis J. DeHaven.
1973. A contribution toward a bibliography on the starling (*Sturnus vulgaris*). 92 p. U.S. Dep. Inter., Bur. Sport Fish. and Wildl., Denver Wildl. Res. Cent., Denver, Colo.

Denton, Samuel Jonathon.
1976. Status of prairie falcon breeding in Oregon. M.S. thesis. Oreg. State Univ., Corvallis. 58 p.

Derickson, W. Kenneth.
1976. Ecological and physiological aspects of reproductive strategies in two lizards. Ecology 57(3):445-458.

Dexter, R. W.
1961. Further studies on nesting of the common night hawk. Bird Banding 32:79-85.

Dexter, Ralph W.
1975. Further studies on the incursions of evening grosbeaks into northeastern Ohio, 1972-1974. Inland Bird Banding News 47(3):102-107.

Dick, James A., and James D. Rising.
1965. A comparison of foods eaten by eastern kingbirds and western kingbirds in Kansas. Kans. Ornithol. Soc. Bull. 16(4):23-24.

Ditmars, Raymond Lee.
1936. The reptiles of North America: A review of the crocodilians, lizards, snakes, turtles, and tortoises inhabiting the United States and northern Mexico. 476 p. Doubleday, Doran, Garden City, N.Y.

Dixon, Clara L.
1978. Breeding biology of the savannah sparrow on Kent Island. Auk 95(2):235-246.

Dixon, Keith L.
1961. Habitat distribution and niche relationships in North American species of *Parus*. *In* Vertebrate speciation: A University of Texas symposium, p. 179-216. W. F. Blair, ed. Univ. Texas Press, Austin.

Dolbeer, Richard A.
1978. Movement and migration patterns of red-winged blackbirds: a continental overview. Bird Banding 49(1):17-34.

Dolton, David D., Compiler.
1977. Mourning dove status report, 1976. U.S. Fish and Wildl. Serv. Spec. Rep. Wildl. 208, 27 p.

Donaldson, J. L., and A. T. Bergerud.
1974. Behavior and habitat selection of an insular population of blue grouse. Syesis 7:115-127.

Drewien, Roderick C., and Elwood G. Bizeau.
1974. Status and distribution of greater sandhill cranes in the Rocky Mountains. J. Wildl. Manage. 38(4):720-742.

Duebbert, Harold F., and John T. Lokemoen.
1977. Upland nesting of American bitterns, marsh hawks, and short-eared owls. Prairie Nat. 9(3 & 4):33-40.

Dunkle, Sidney W.
1977. Swainson's hawks on the Laramie Plains, Wyoming. Auk 94(1):65-71.

Dzubin, A., H. Boyd, and W. J. D. Stephen.
1975. Blue and snow goose distribution in the Mississippi and central flyways, 1951-71. Can. Wildl. Serv. Prog. Notes 54, 34 p. Ottawa.

Easterla, David A.
1971. Notes on young and adults of the spotted bat, *Euderma maculatum*. J. Mammal. 52(2):475-476.

Egoscue, Harold J.
1960. Laboratory and field studies of the northern grasshopper mouse. J. Mammal. 41(1):99-110.

Egoscue, Harold J.
1962. Ecology and life history of the kit fox in Tooele County, Utah. Ecology 43(3):481-497.
Egoscue, Harold J.
1964. Ecological notes and laboratory life history of the canyon mouse. J. Mammal. 45(3):387-396.
Egoscue, Harold J.
1975. Population dynamics of the kit fox in western Utah. South. Calif. Acad. Sci. Bull. 74(3):122-127.
Einarsen, Arthur Skogman.
1941. The effect upon the black tern of a change in its habitat. Murrelet 22(1):19.
Ellarson, R. S.
1956. A study of the oldsquaw duck on Lake Michigan. Ph. D. thesis. Univ. Wis., Milwaukee. 231 p.
Ellison, Laurence N., and Lynn Cleary.
1978. Effects of human disturbance on breeding of double-crested cormorants. Auk 95(3):510-517.
Emlen, John T., Jr.
1952. Territory, nest building, and pair formation in the cliff swallow. Auk 71(1):16-35.
Emlen, Stephen T., James D. Rising, and William L. Thompson.
1975. A behavioral and morphological study of sympatry in the indigo and lazuli buntings of the Great Plains. Wilson Bull. 87(2):145-179.
Enderson, James Harris.
1960. A population study of the sparrow hawk in east-central Illinois. Wilson Bull. 72(3):222-231.
Erickson, Ray Charles.
1948. Life history and ecology of the canvas-back, *Nyroca valisineria* (Wilson), in southeastern Oregon. Iowa State Coll. J. Sci. 23(1):30-32.
Eriksson, K.
1970. The autumn migration and wintering ecology of the siskin, *Carduelis spinus*. Ornis Fenn. 47:52-68.
Erpino, M. J.
1968. Nest-related activities of black-billed magpies. Condor 70:154-165.
Errington, Paul L.
1943. An analysis of mink predation upon muskrats in north-central United States. Iowa Agric. Exp. Stn. Res. Bull. 320, p. 797-924. Ames.
Erskine, A. J., and W. D. McLaren.
1972. Sapsucker nest holes and their use by other species. Can. Field-Nat. 86(4):357-361.
Erskine, Anthony J.
1961. Nest-site tenacity and homing in the bufflehead. Auk 78(3):389-396.
Erskine, Anthony John.
1960. A discussion of the distributional ecology of the bufflehead (*Bucephala albeola*; Anatidae; Aves) based upon breeding biology studies in British Columbia. M.S. thesis. Univ. B.C., Vancouver. 116 p.
Erskine, Anthony John.
1972. Populations, movements and seasonal distributions of mergansers in northern Cape Breton Island. Can. Wildl. Serv. Rep. Ser. 17, 36 p.
Ervin, Stephen.
1977. Flock size, composition, and behavior in a population of bushtits (*Psaltriparus minimus*). Bird Banding 48(2):97-191.
Evanden, Fred G., Jr.
1950. Unusual singing perches of the winter wren. Murrelet 31(2):32-33.
Evans, P. R.
1969. Ecological aspects of migration and pre-migratory fat deposition in the lesser redpoll, *Carduelis flammea cabaret*. Condor 71:316-330.
Faaborg, John.
1976. Habitat selection and territorial behavior of the small grebes of North Dakota. Wilson Bull. 88(3):390-399.
Farner, D. S., and J. Kezer.
1955. Life history patterns of the salamander, *Ambystoma macrodactylum*, in the high Cascade Mountains of southern Oregon. Copeia 1955:127-131.
Farner, Donald S.
1949. Age groups and longevity in the American robin: Comments, further discussion, and certain revisions. Wilson Bull. 61(2):68-81.

Feerer, J. L., and R. L. Garret.
1977. Potential western grebe extinction on California lakes. Cal-Neva Wildl. Trans. 1977:80-89.

Fenton, M. Brock.
1970. Population studies of *Myotis lucifugus* (Chiroptera; Vespertilionidae) in Ontario. Life Sci. Contrib. 77, 34 p. R. Ont. Mus.

Fenton, M. Brock.
1972. Distribution and overwintering of *Myotis leibii* and *Eptesicus fuscus* (Chiroptera; Vespertilionidae) in Ontario. Life Sci. Occas. Pap. 21, 8 p. R. Ont. Mus., Toronto.

Ffolliott, Peter F.
1976. Observations of beaver activity in an extreme environment. Southwest. Nat. 21(1):123-139.

Ficken, M. S., and R. W. Ficken.
1962a. The comparative ethology of the wood warblers: A review. Living Birds 1:103-122.

Ficken, M. S., and R. W. Ficken.
1962b. Some aberrant characters of the yellow-breasted chat, *Icteria virens*. Auk 79:718-719.

Ficken, Millicent S., and Robert Ficken.
1967. Age-specific differences in the breeding behavior and ecology of the American redstart. Wilson Bull. 79(1):188-199.

Ficken, Millicent S., and Robert W. Ficken.
1965. Comparative ethology of the yellow warbler, chestnut-sided warbler and American redstart. Wilson Bull. 77(4):363-375.

Findley, James F., and Clyde Jones.
1964. Seasonal distribution of the hoary bat. J. Mammal. 45(3):461-470.

Findley, Robert B.
1958. The woodrats of Colorado: Distribution and ecology. Univ. Kans. Mus. Nat. Hist. Publ. 10(6):213-552.

Fisler, George F.
1971. Age structure and sex ratio in populations of *Reithrodontomys*. J. Mammal. 52(4):653-662.

Fitch, Henry S.
1956. An ecological study of the collared lizard (*Crotaphytus collaris*). Univ. Kans. Mus. Nat. Hist. Publ. 8(3):213-274.

Fitch, Henry S.
1963. Natural history of the race *Coluber constrictor*. Univ. Kans. Mus. Nat. Hist. Publ. 15(8):351-468.

Fitch, Henry S., Freeman Swenson, and Daniel F. Tillotson.
1946. Behavior and food habits of the red-tailed hawk. Condor 48(5):205-237.

Fitch, Henry Sheldon.
1965. An ecological study of the garter snake. *Thamnophis sirtalis*. Univ. Kans. Mus. Nat. Hist. Publ. 15(10):493-564.

Fitzner, R. E.
1978. Behavioral ecology of the Swainson's hawk (*Buteo swainsoni*) in southeastern Washington. Ph. D. thesis. Wash. State Univ., Pullman. 194 p.

Fjeldsa, J.
1973a. Feeding and habitat selection of the horned grebe, *Podiceps auritus* (Aves), in the breeding season. Vidensk. Medd. Dan. Naturhist. Foren. Kjobenhaven 136:57-95.

Fjeldsa, J.
1973b. Territory and the regulation of population density and recruitment in the horned grebe *Podiceps auritus arcticus* Boje, 1822. Vidensk. Medd. Dan. Naturhist. Foren. Kjobenhaven 136:117-189.

Fletcher, Lauriel E., and Douglas G. Smith.
1978. Some parameters of song important in conspecific recognition by grey catbirds. Auk 95(2):338-347.

Forbes, James E., and Dwain W. Warner.
1974. Behavior of a radio-tagged saw-whet owl. Auk 91(4):783-795.

Fox, Glen A.
1971. Recent changes in the reproductive success of the pigeon hawk. J. Wildl. Manage. 35(1):122-128.

Fox, Wade.
1948. Effect of temperature on development of scutellation in the garter snake, *Thamnophis elegans atratus*. Copeia 1948(4):252-262.

Fox, Wade.
1951. Relationships among the garter snakes of the *Thamnophis elegans* Rassenkreis. Univ. Calif. Publ. Zool. 50(5):485-530.

Frederickson, L. H.
1970. Breeding biology of American coots in Iowa. Wilson Bull. 82(4):445-457.

Freer, Valerie Misner.
1977. Colony structure and function in the bank swallow, *Riparia riparia*, L. Ph. D. thesis. State Univ. New York, Binghampton, 165 p.

Friedman, H.
1963. Host relations of the parasitic cowbirds. U.S. Nat. Mus. Bull. 233, 276 p.

Fritzell, Erik K.
1978. Habitat use by prairie raccoons during the waterfowl breeding season. J. Wildl. Manage. 42(1):118-127.

Fuller, Robert W.
1953. Studies in the life history and ecology of the American pintail (*Anas acuta tzitzihoa* Vieillot) in Utah. M.S. thesis. Utah State Univ., Logan. 181 p.

Fyfe, Richard W., and Richard R. Olendorff.
1976. Minimizing the dangers of nesting studies to raptors and other sensitive species. Can. Wildl. Serv. Occas. Pap. 23, 16 p.

Gabrielson, Ira Noel, and Stanley G. Jewett.
1970. Birds of the Pacific Northwest: With special references to Oregon. 650 p. Dover Publ., Inc., New York.

Galbreath, Donald S., and Raleigh Moreland.
1953. The chuckar partridge in Washington. Wash. State Game Dep. Biol. Bull. 11, 55 p. Olympia.

Garrott, Robert A., and Donald A. Jenni.
1978. Arboreal behavior of yellow-bellied marmots. J. Mammal. 59(2):433-434.

Gashwiler, Jay S.
1976. A new distribution record of Merriam's shrew in Oregon. Murrelet 57(1):13-14.

Gashwiler, Jay S., W. Leslie Robinette, and Owen W. Morris.
1961. Breeding habits of bobcats in Utah. J. Mammal. 42(1):76-84.

Gass, Clifton Lee, George Angehr, and Janice Centa.
1976. Regulation of food supply by feeding territoriality in the rufous hummingbird. Can. J. Zool. 54(12):2046-2054.

Gates, John M.
1958. A study of the breeding behavior of the gadwall in northern Utah. M.S. thesis. Utah State Univ., Logan. 124 p.

Gates, John M.
1962. Breeding biology of the gadwall in northern Utah. Wilson Bull. 74(1):43-67.

Gates, John M.
1972. Red-tailed hawk populations and ecology in east-central Wisconsin. Wilson Bull. 84(4):421-433.

Gehrman, Kenneth Henry.
1951. An ecological study of the lesser scaup duck (*Aythya affinis eyton*) at West Medical Lake, Spokane County, Washington. M.S. thesis. Wash. State Univ., Pullman. 94 p.

Gerstenberg, R. H., and R. M. Jurek, Compilers.
1972. Selected references on shore birds. Calif. Dep. Fish and Game. 47 p.

Ghiselin, J.
1970. Edaphic control of habitat selection by kangaroo mice (Microdipodops) in three Nevadan populations. Oecologia (Berl.) 4:248-261.

Gibb, J. A.
1956. Food, feeding habits and territory of the rock pipit, *Anthus spinoletta*. Ibis 98:506-530.

Gibbs, Richard M.
1961. Breeding ecology of the common goldeneye, *Bucephala clangula americana*, in Maine. M.S. thesis. Univ. Maine, Orono. 113 p.

Gibson, F.
1971. The breeding biology of the American avocet (*Recurvirostra americana*) in central Oregon. Condor 73:444-454.

Gier, H. T.
1968. Coyotes in Kansas. Agric. Exp. Stn. Bull. 393, 96 p. Kans. State Coll. Agric. and Appl. Sci., Manhattan.

Gilmer, David S., I. J. Ball, Lewis M. Cowardin, John E. Mathisen, and John H. Riechmann.
1978. Natural cavities used by wood ducks in north-central Minnesota. J. Wildl. Manage. 42(2):288-298.

Girard, George L.
1939. Notes on life history of the shoveler. North Am. Wildl. Conf. Trans. 4:364-371.

Giuntoli, Mervin, and Richard L. Mewaldt.
1978. Stomach contents of Clark's nutcrackers collected in western Montana. Auk 95(3):595-598.

Glahn, James F.
1974. Study of breeding rails with recorded calls in north-central Colorado. Wilson Bull. 86(3):206-214.

Glover, Fred A.
1953. Nesting ecology of the pied-billed grebe in northwestern Iowa. Wilson Bull. 65(1):32-39.

Glue, David E.
1977. Breeding biology of long-eared owls. Br. Birds 70(8):318-331.

Goldberg, Stephen R.
1971. Reproduction in the short-horned lizard *Phrynosoma douglassi* in Arizona. Herpetologica 27(3):311-314.

Gollob, Timothy, and Warren Pulich, Sr.
1978. Bullfrogs preying on cedar waxwings. Herpetol. Rev. 9(2):47-48.

Good, Ernest E.
1952. The life history of the American crow, *Corvus brachyrhynchos*. Ph. D. diss. Ohio State Univ., Columbus. 195 p.

Gordon, Kenneth.
1943. The natural history and behavior of the western chipmunk and the mantled ground squirrel. Oreg. State Monogr., Stud. Zool. 5, 104 p. Oreg. State Coll. [Univ.] Press, Corvallis.

Gottfried, Bradley M., and Edwin C. Franks.
1975. Habitat use and flock activity of dark-eyed juncos in winter. Wilson Bull. 87(3):374-383.

Graham, R. E.
1966. Observations on the roosting habits of the big-eared bat, *Plecotus townsendii*, in California limestone caves. Cave Notes 8(3):17-22.

Graul, Walter D.
1975. Breeding biology of the mountain plover. Wilson Bull. 87(1):6-31.

Gray, Gene Mack.
1967. An ecological study of sage grouse broods with reference to nesting, movements, food habits, and sagebrush strip spraying in the Medicine Lodge drainage, Clark County, Idaho. M.S. thesis. Univ. Idaho, Moscow. 200 p.

Greenhalgh, Clifton M.
1952. Food habits of the California gull in Utah. Condor 54(5):302-308.

Greenlaw, Jon S.
1978. The relation of breeding schedule and clutch size to food supply in the rufous-sided towhee. Condor 80(1):24-33.

Greenwald, O. E.
1974. Thermal dependence of striking and prey capture by gopher snakes. Copeia 1974(1):141-148.

Greenwalt, C. H.
1960. Hummingbirds. 250 p. Am. Mus. Nat. Hist. Doubleday, Garden City, N.Y.

Griffee, W. E.
1954. Some Oregon nesting records. Murrelet 35(3):48-49.

Griffee, W. E.
1958. Notes on nesting of American merganser and Barrow's goldeneye. Murrelet 39(2):26.

Griffee, W. E.
1961a. Bufflehead nesting records for Oregon. Murrelet 42(1):5.

Griffee, W. E.
1961b. Nesting of the northern Vaux swift in the Willamette Valley. Murrelet 42(2):25-26.

Grinnell, J., and Wm. H. Behle.
1935. Comments upon the subspecies of *Catherpes mexicanus*. Condor 37(5):247-251.

Griscom, Ludlow, and Alexander Sprunt, Jr.
1957. The warblers of America: A popular account of the wood warblers as they occur in the western hemisphere. 356 p. Devin-Adair Co., New York.

Gross, Jack E., L. Charles Stoddart, and Frederic H. Wagner.
1974. Demographic analysis of a northern Utah jackrabbit population. Wildl. Monogr. 40, 68 p.

Gutierrez, R. J.
1975. Literature review and bibliography of the mountain quail (*Oreortyx pictus*). USDA For. Serv. Calif. Reg. 5, 33 p. San Francisco.
Haecker, Fred W.
1948. A nesting study of the mountain bluebird in Wyoming. Condor 50(5):216-219.
Hall, E. Raymond.
1951. American weasels. Univ. Kans. Mus. Nat. Hist. Publ. 4:1-466.
Hall, Eugene Raymond.
1946. Mammals of Nevada. 710 p. Univ. Calif. Press, Berkeley.
Hall, Eugene Raymond, and Keith R. Kelson.
1959. The mammals of North America. 2 vols. 1,078 p. Ronald Press Co., New York.
Hamas, Michael J.
1974. Human incursion and nesting sites of the belted kingfisher. Auk 91(4):835-836.
Hamerstrom, Frances.
1969. A harrier population study. *In* Peregrine falcon populations, p. 367-383, J. J. Hickey, ed. Univ. Wis. Press, Madison.
Hamilton, Terrell H.
1962. Species relationships and adaptations for sympatry in the avian genus *Vireo*. Condor 64(1):40-68.
Hamilton, W. J., Jr.
1933. The weasels of New York: Their natural history and economic status. Am. Midl. Nat. 14(4):289-344.
Hansen, Charles Goodman.
1956. An ecological survey of the vertebrate animals on Steen's Mountain, Harney County, Oregon. Ph. D. thesis. Oreg. State Univ., Corvallis. 199 p.
Hansen, Edward L., and Bernie E. Carter.
1963. A nesting study of Brewer's blackbirds in Klamath County, Oregon. Murrelet 44(2):18-21.
Hansen, R. M.
1972. Estimation of herbage intake from jackrabbit feces. J. Range Manage. 25(6):468-471.
Hansen, R. M., and R. F. Beck.
1968. Habitat of pocket gophers in Cochetopa Creek drainage, Colorado. Am. Midl. Nat. 79(1):103-117.
Harcus, John Leslie.
1973. Song studies in the breeding biology of the catbird, *Dumetella carolinensis* (Aves: Mimidae). Ph. D. thesis. Univ. Toronto, Toronto. 329 p.
Harris, Bruce K.
1975. Pine siskins: Widespread distribution during 1973 breeding season. S.D. Bird Notes 27(1):4, 18.
Harris, J. A.
1970. Bat-guano cave environment. Science 169(3952):1342-1343.
Harris, S. W.
1952. An ecological study of the waterfowl of the potholes area Grant County, Washington. M.S. thesis. Wash. State Univ., Pullman. 201 p.
Harvey, Michael J.
1976. Status of endangered bats in the Blanchard Springs Caverns area. *In* National cave management symposium proceedings, p.63, Tom Aley and Doug Rhodes, eds. Speleobooks, Albuquerque, N.M.
Haskell, Horace S., and Hudson G. Reynolds.
1947. Growth, developmental food requirements, and breeding activities of the California jackrabbit. J. Mammal. 28(2):129-136.
Heath, James Edward.
1965. Temperature regulation and diurnal activity in horned lizards. Univ. Calif. Publ. Zool. 64:97-136.
Hebrard, James Jack.
1978. Habitat partitioning in two species of *Spizella* (Aves: Emberizidae): A concurrent laboratory and field study. Ph. D. thesis. Clemson Univ., Clemson, S.C. 39 p.
Hedlund, J. D., D. T. McCullugh, and W. H. Rickard.
1975. Mouse populations on knob and kettle topography in south-central Washington. Northwest Sci. 49(4):253-260.
Heidt, Gary A., Ann U. Shump, Karl A. Shump, Jr., and Richard J. Aulerich.
1976. A bibliography of mustelids, part IV: Weasels. Mich. Agric. Exp. Stn. 7662, 47 p. Mich. State Univ., East Lansing.

Henny, C. J., and H. M. Wight.
1972. Population ecology and environmental pollution: Red-tailed and Cooper's hawks. *In* Population ecology of migratory birds: A symposium, p. 229-250. U.S. Dep. Inter., Bur. Sport Fish. and Wildl., Wildl. Res. Rep. 2.

Henny, Charles J.
1969. Geographical variation in mortality rates and production requirements of the barn owl (*Tyto alba* ssp.). Bird Banding 40(4):277-356.

Henny, Charles J.
1972. An analysis of the population dynamics of selected avian species, with special reference to changes during the modern pesticide era. U.S. Dep. Inter., Bur. Sport Fish. and Wildl. Serv., Wildl. Res. Rep. 1, 99 p.

Henny, Charles J.
1977. Research, management and status of the osprey in North America. *In* Proceedings of the world birds of prey conference, p. 199-222. R. D. Chancellor, ed. Vienna.

Henny, Charles J., and Michael R. Bethers.
1971. Population ecology of the great blue heron with special reference to western Oregon. Can. Field-Nat. 85(3):205-209.

Henny, Charles J., James A. Collins, and William J. Deibert.
1978. Osprey distribution, abundance and status in western North America: II. The Oregon population. Murrelet 59(1):14-25.

Herlugson, Christopher J.
1978. Comments on the status and distribution of western and mountain bluebirds in Washington. West. Birds 9:21-32.

Herman, Steven G.
1971. The functional and numerical responses of the Cassin finch, *Carpodacus cassinii* Barid, to epidemic numbers of the lodgepole needleminer, *Coleotechnites milleri* (Busck). Wasmann J. Biol. 29(1):71-80.

Herzog, Harold A., Jr., and Gordon M. Burghardt.
1974. Prey movement and predatory behavior of juvenile western yellow-bellied racers, *Coluber constrictor mormon*. Herpetologica 30(3):285-289.

Hespenheide, Henry A.
1964. Competition and the genus *Tyrannus*. Wilson Bull. 76(3):265-281.

Heydweiller, A. Marguerite.
1935. A comparison of winter and summer territories and seasonal variations of the tree sparrow (*Spizella arborea*). Bird Banding 6(1):1-11.

Hickey, Joseph J., Ed.
1969. Peregrine falcon populations: Their biology and decline. 596 p. Univ. Wis. Press, Madison.

Hill, Richard A.
1976. Host-parasite relationships of the brown-headed cowbird in a prairie habitat of west-central Kansas. Wilson Bull. 88(4):555-565.

Himes, James E.
1977. Nesting and brood ecology of lesser scaup at Waterhen Marsh, Saskatchewan. Can. Field-Nat. 91(3):248-255.

Hine, Ruth L., Betty L. Les, Bruce F. Hellmich, and Richard C. Vogt.
1975. Preliminary report on leopard frog (*Rana pipiens*) populations in Wisconsin. Dep. Nat. Resour. Res. Rep. 81, 31 p. Madison, Wis.

Hochbaum, Hans Albert.
1944. The canvasback on a prairie marsh. 201 p. Am. Wildl. Inst., Washington, D.C.

Hodson, Keith A.
1976. The ecology of Richardson's merlin on the Canadian prairies. M.S. thesis. Univ. B.C., Vancouver. 83 p.

Hoff, C. C., and L. L. Riedesel.
1969. Temperature relationships of the western pipistrelle (*Pipistrellus hesperus*). Physiol. Syst. Semiarid Environ., p. 85-96, Univ. N.M. Press.

Hoffman, Robert D., and Harold H. Prince.
1975. Vegetative structure and nest distribution in a black-crowned night heron heronry. Jack-Pine Warbler 53(3):95-99.

Hoffman, Robert S., and Robert D. Fisher.
1978. Additonal distributional records of Preble's shrew (*Sorex preblei*). J. Mammal. 59(4):883-884.

Hofslund, P. B.
1959. A life history study of the yellow throat, *Geothlypis trichas*. Minn. Acad. Sci. Proc. 27:144-174.

Hohn, E. Otto.
1967. Observations on the breeding biology of Wilson's phalarope (*Steganopus tricolor*) in central Alberta. Auk 84(2):220-244.

Hohn, E. Otto.
1971. Observations on the breeding behaviour of grey and red-neck phalaropes. Ibis 113(3):335-348.

Holcomb, Larry C.
1969. Breeding biology of the American goldfinch in Ohio. Bird Banding 40(1):26-44.

Hollenbeck, Robert Rudolph.
1974. Growth rates and movements within a population of *Rana pretiosa pretiosa* Baird and Girard in south-central Montana. Ph. D. thesis. Mont. State Univ., Bozeman. 74 p.

Hooven, E. F., R. F. Hoyer, and R. M. Storm.
1975. Notes on the vagrant shrew, *Sorex vagrans*, in the Willamette Valley of western Oregon. Northwest Sci. 49(3):163-173.

Hooven, Edward F.
1971. The porcupine in Oregon: Its life history and control. For. Res. Lab. Res. Pap. 10, 22 p. Oreg. State Univ., Corvallis.

Horak, Gerald Joseph.
1964. A comparative study of Virginia and sora rails with emphasis on foods. M.S. thesis. Iowa State Univ., Ames. 73 p.

Horn, Everett E.
1923. Some notes concerning the breeding habits of *Thomomys townsendi*, observed near Vale, Malheur County, Oregon, during the spring of 1921. J. Mammal. 4(1):37-39.

Horn, Henry S.
1968. The adaptive significance of colonial nesting in the Brewer's blackbird (*Euphagus cyanocephalus*). Ecology 49(4):682-694.

Horn, Kirk M., and David B. Marshall.
1975. Status of poor-will in Oregon and possible extension due to clearcut timber harvest methods. Murrelet 56(1):4-5.

Hornocker, Maurice G.
1970. An analysis of mountain lion predation upon mule deer and elk in the Idaho primitive area. Wildl. Monogr. 21, 39 p.

Horvath, Otto.
1964. Seasonal differences in rufous hummingbird nest height and their relation to nest climate. Ecology 45(2):235-241.

Hubbard, John P.
1969. The relationships and evolution of the *Dendroica coronata* complex. Auk 86(3):393-432.

Humphrey, Stephen R., and Thomas H. Kunz.
1976. Ecology of a Pleistocene relict, the western big-eared bat (*Plecotus townsendii*), in the southern Great Plains. J. Mammal. 57(3):470-494.

Hunt, G. L.
1972. Influence of food distribution and human disturbance on the reproductive success of herring gulls. Ecology 53(6):1051-1061.

Ingles, Lloyd G.
1961. Home range and habitats of the wandering shrew. J. Mammal. 42(4):455-462.

Jackman, Siri M., and J. Michael Scott.
1975. Literature review of twenty-three selected forest birds of the Pacific Northwest. 382 p. USDA For. Serv. Reg. 6, Portland, Oreg.

Jackman, Siri Marion.
1974. Woodpeckers of the Pacific Northwest; their characteristics and their role in the forests. M.S. thesis. Oreg. State Univ., Corvallis. 147 p.

Jackson, J. A.
1970. A quantitative study of the foraging ecology of downy woodpeckers. Ecology 51(2):318-323.

Jackson, Jerome A., and Phillip G. Burchfield.
1975. Nest-site selection of barn swallows in east-central Mississippi. Am. Midl. Nat. 94:503-509.

Jackson, Jerome A., Irvine D. Prather, Richard N. Conner, and Sheila Parness Gaby.
1978. Fishing behavior of black and turkey vultures. Wilson Bull. 90(1):141-143.

Jahn, Laurence Roy.
1965. Duck and coot ecology and management in Wisconsin. Ph. D. thesis. Univ. Wis., Madison. 856 p.

James, Frances C., and H. H. Shugart, Jr.
1974. The phenology of the nesting season of the American robin (*Turdus migratorius*) in the United States. Condor 76(2):159-168.

James, Ross D.
1976. Foraging behavior and habitat selection of three species of vireos in southern Ontario. Wilson Bull. 88(1):62-75.

James, Ross David.
1973. Ethological and ecological relationships of the yellow-throated and solitary vireos (Aves: Vireonidae) in Ontario. Ph. D. thesis. Univ. Toronto, Toronto. 274 p.

James, Ted R., and Robert W. Seabloom.
1969a. Reproductive biology of the white-tailed jackrabbit in North Dakota. J. Wildl. Manage. 33(3):558-568.

James, Ted R., and Robert W. Seabloom.
1969b. Aspects of growth in the white-tailed jackrabbit. N.D. Acad. Sci. Proc. 23:7-14.

Jameson, David L.
1956. Growth, dispersal and survival of the Pacific treefrog. Copeia 1956(1):25-29.

Jameson, David L., William Taylor, and John Mountjoy.
1970. Metabolic and morphological adaptation to heterogenous environments by the Pacific tree toad, *Hyla regilia*. Evolution 24(1):75-89.

Jarvis, Robert L., and Stanley W. Harris.
1967. Canada goose nest success and habitat use at Malheur Refuge. Murrelet 48(3):46-51.

Jenni, D. A.
1969. A study of the ecology of 4 species of herons during the breeding season at Lake Alice, Alachua County, Florida. Ecol. Monogr. 39:245-270.

Jensen, G. Hortin.
1949. Migration of the gadwall. *In* Migration of some North American waterfowl. U.S. Fish and Wildl. Serv. Spec. Sci. Rep. Wildl. 1:9-10.

Jewett, Stanley G.
1949. The Franklin gull in Oregon. Condor 51(4):189-190.

Johns, J. E.
1969. Field studies of Wilson's phalarope. Auk 86(4):660-670.

Johnson, Mark K.
1977. Foods of Townsend ground squirrels on the Arid Land Ecology Reserve (Washington). Great Basin Nat. 37(1):128.

Johnson, Mark K., and Richard M. Hansen.
1979. Foods of cottontails and woodrats in south-central Idaho. J. Mammal. 60(1):213-215.

Johnson, Murray L., and C. Wesley Clanton.
1954. Natural history of *Sorex merriami* in Washington State. Murrelet 35(1):1-4.

Johnson, Murray L., C. Wesley Clanton, and John Girard.
1948. The sagebrush vole in Washington State. Murrelet 29(3):44-47.

Johnson, Ned K.
1963. Biosystematics of sibling species of flycatchers in the *Empidonax hammondii-oberholseri-wrightii* complex. Univ. Calif. Publ. Zool. 66(2):79-238.

Johnson, Robert F., Jr., and Norman F. Sloan.
1978. White pelican production and survival of young at Chase Lake National Wildlife Refuge, North Dakota. Wilson Bull. 90(3):346-352.

Jollie, Malcolm.
1976. Species interrelationships of three corvids. Biologist 58(3):89-111.

Jones, Clyde.
1965. Ecological distribution and activity periods of bats of the Mogollon Mountains area of New Mexico and adjacent Arizona. Tulane Stud. Zool. 12(4):93-100.

Jones, Gwilym S., John O. Whitaker, Jr., and Chris Maser.
1978. Food habits of jumping mice (*Zapus trinotatus* and *Z. princeps*) in western North America. Northwest Sci. 52(1):57-60.

Jones, J. C.
1940. Food habits of the American coot with notes on distribution. U.S. Dep. Inter. Biol. Surv., Bur. Wildl. Res. Bull. 2, 52 p.

Jones, R. E.
1960. Activities of the magpie during the breeding period in southern Idaho. Northwest Sci. 34:18-25.

Jorgensen, C. D.
1963. Spatial and time distribution of *Dipodomys microps occidentalis* within distinct plant communities. Ecology 44(1):183-187.

Julander, Odell, Jessop B. Low, and Owen W. Morris.
1969. Pocket gophers on seeded Utah mountain range. J. Range Manage. 22(5):325-329.

Kale, Herbert W., II.
1965. Ecological and bioenergetics of the long-billed marsh wren in Georgia salt marshes. Nuttall Ornithol. Club Publ. 5, 142 p. Cambridge, Mass.

Kebbe, Chester E.
1958. Nesting records of the red-necked grebe in Oregon. Murrelet 39(1):14.

Kebbe, Chester E.
1959. Nesting records of saw-whet owls in Oregon. Murrelet 40(2):21.

Keith, James H.
1977. Underground nature preserves in Indiana. *In* National cave management symposium proceedings, p. 16-17. Tom Aley and Doug Rhodes, eds. Speleobooks, Albuquerque, N.M.

Kenagy, G. J.
1973. Adaptations for leaf eating in the Great Basin kangaroo rat, *Dipodomys microps*. Oecologia (Berl.) 12:383-412.

Kendeigh, S. Charles.
1941. Territorial and mating behavior of the house wren. Ill. Biol. Monogr. 18(3), 120 p.

Kendeigh, S. Charles, Chairman.
1973. A symposium on the house sparrow (*Passer domesticus*) and European tree sparrow (*P. montanus*) in North America. Ornithol. Monogr. 14, 121 p. Am. Ornithol. Union. [Anchorage, Ky.]

Kennard, John H.
1976. A biennial rhythm in the winter distribution of the common redpoll. Bird Banding 47(3):231-237.

Kerbes, R. H.
1975. The nesting population of lesser snow geese in the eastern Canadian arctic: A photographic inventory of June 1973. Can. Wildl. Serv. Rep. Ser. 35, 47 p. Ottawa.

Kessel, Brina.
1976. Winter activity patterns of black-capped chickadees in interior Alaska. Wilson Bull. 88(1):36-61.

Kilham, Lawrence.
1968a. Reproductive behavior of hairy woodpeckers: II. Nesting and habitat. Wilson Bull. 80(3):286-305.

Kilham, Lawrence.
1968b. Reproductive behavior of white-breasted nuthatches: I. Distraction display, bill-sweeping, and nest-hole defense. Auk 85(3):477-492.

Kilham, Lawrence.
1971a. Reproductive behavior of yellow-bellied sapsuckers: I. Preference for nesting in Fomes-infected aspens and nest hole interrelations with flying squirrels, raccoons, and other animals. Wilson Bull. 83(2):159-171.

Kilham, Lawrence.
1971b. Roosting habits of white-breasted nuthatches. Condor 73(1):113-114.

Kilham, Lawrence.
1972. Reproductive behavior of white-breasted nuthatches: II. Courtship. Auk 89(1):115-129.

Kilham, Lawrence.
1973. Reproductive behavior of the red-breasted nuthatch: I. Courtship. Auk 90(3):597-609.

Kilham, Lawrence.
1974. Biology of young belted kingfishers. Am. Midl. Nat. 92(1):245-247.

Kindschy, Robert R., and Chris Maser.
1978. Jordan Crater Research Natural Area. p. JC-1 to JC-18. Supplement No. 7 to "Federal Research Natural Areas in Oregon and Washington: A guidebook for scientists and educators," by Jerry F. Franklin, Frederick C. Hall, C. T. Dyrness, and Chris Maser. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Kindschy, Robert R., Jr.
1964. Ecological studies on the rock dove in southeastern Oregon. Northwest Sci. 38(4):138-140.

King, James R.
1955. Notes on the life history of Traill's flycatcher (*Empidonax trailii*) in southeastern Washington. Auk 72(2):148-173.

King, John Arthur, Ed.
1968. Biology of *Peromyscus* (Rodentia). Am. Soc. Mammal. Spec. Publ. 2, 593 p. Stillwater, Okla.

Kirby, Ronald E.
1976. Breeding of chronology and interspecific relations of pied-billed grebes in northern Minnesota. Wilson Bull. 88(3):493-495.
Kiss, B. J., and I. Sterbetz.
1973. Comparative data of the nutrition of grebes (Podicipidae) at the Tisza. Tiscia 8:65-70.
Kitchen, David W.
1974. Social behavior and ecology of the pronghorn. Wildl. Monogr. 38, 96 p.
Kitchen, David Wayne.
1968. Brood habitat selection of the hooded merganser (*Lophodytes cucullatus*) in northeastern Wisconsin. M.S. thesis. Univ. Mich., Ann Arbor. 80 p.
Kiviat, Erik.
1978. Vertebrate use of muskrat lodges and burrows. Estuaries 1(3):196-200.
Klauber, Lawrence Monroe.
1972. Rattlesnakes: Their habits, life histories, and influence on mankind. 2d ed. 2 vols. 1,533 p. Univ. Calif., Berkeley.
Klopfer, Peter H.
1965. Behavioral aspects of habitat selection: A preliminary report on stereotype in foliage preference of birds. Wilson Bull. 77(4):376-381.
Kluyver, H. N.
1961. Food consumption in relation to habitat in breeding chickadees. Auk 78(4):532-550.
Knapton, Richard W., and John R. Krebs.
1974. Settlement patterns, territory size, and breeding density in the song sparrow (*Melospiza melodia*). Can. J. Zool. 52(11):1413-1420.
Knapton, Richard W., and Donald A. Sexton.
1978. Winter courtship behavior in Bohemian waxwings. Blue Jay 36(3):164-165.
Knopf, Fred L.
1975. Spatial and temporal aspects of colonial nesting of the white pelican, *Pelecanus erythrorhynchos*. Ph. D. thesis. Utah State Univ., Logan. 77 p.
Knowlton, Frederick F.
1972. Preliminary interpretations of coyote population mechanics with some management implications. J. Wildl. Manage. 36(2):369-382.
Krapu, Gary L.
1977. Pintail reproductions hampered by snowfall and agriculture. Wilson Bull. 89(1):154-157.
Krapu, Gary L.
1978. Productivity of red-winged blackbirds in prairie pothole habitat. Iowa Bird Life 40:24-30.
Krear, Harry Robert.
1965. An ecological and ethological study of the pika (*Ochotona princeps saxatilis* Bangs) in the front range of Colorado. Ph. D. thesis. Univ. Colo., Boulder. 329 p.
Krebs, John R.
1974. Colonial nesting and social feeding as strategies for exploiting food resources in the great blue heron (*Ardea herodias*). Behaviour 51(1-2):99-134.
Kritzman, Ellen B.
1974. Ecological relationships of *Peromyscus maniculatus* and *Perognathus parvus* in eastern Washington. J. Mammal. 55(1):172-188.
Kroodsma, Donald E.
1973. Coexistence of Bewick's wrens and house wrens in Oregon. Auk 90(2):341-352.
Kroodsma, Donald E.
1975. Song patterning in the rock wren. Condor 77(3):294-303.
Kroodsma, Roger L.
1974. Species-recognition behavior of territorial male rose-breasted and black-headed grosbeaks (*Pheucticus*). Auk 91(1):54-64.
Krutzsch, Philip H.
1954. Notes on the habits of the bat, *Myotis californicus*. J. Mammal. 35(4):539-545.
Kuerzi, Richard Gottron.
1940-41. Life history studies of the tree swallow. Linn. Soc. N.Y. Proc. 52-53, p. 1-52.
Kunz, Thomas H., Edythe L. P. Anthony, and W. Timothy Rumage III.
1977. Mortality of little brown bats following multiple pesticide applications. J. Wildl. Manage. 41(3):476-483.
Kushlan, James A.
1976. Feeding behavior of North American herons. Auk 93(1):86-94.

Lack, David.
1945. The ecology of closely related species with special reference to cormorant (*Phalacrocorax carbo*) and shag (*P. arsitotelis*). J. Anim. Ecol. 14(1):12-16.

Lahnum, Willard H.
1944. A study of the mountain quail with suggestions for management in Oregon. Ph. D. diss. Oreg. State Coll., Corvallis. 127 p.

Lanyon, Wesley E.
1957. The comparative biology of the meadowlarks (*Sturnella*) in Wisconsin. Nuttall Ornithol. Club 1, 67 p. Cambridge, Mass.

Larsen, Kenneth H., and John H. Dietrich.
1970. Reduction of a raven population on lambing grounds with DRC-1339. J. Wildl. Manage. 34(1):200-204.

Laughrin, Lyndal.
1970. San Joaquin kit fox, its distribution and abundance. Calif. Dep. Fish and Game, Wildl. Manage. Branch. Admin. Rep. 70-2, Fed. Aid Proj. W-54-R, 20 p.

Laun, Charles H.
1957. A life history study of the mountain plover, *Eupoda montana* (Townsend), on the Laramie Plains, Albany County, Wyoming. M.S. thesis. Univ. Wyo., Laramie. 71 p.

Lavers, Norman.
1975. The status of the gray flycatcher in Washington State. West. Birds 6(1):25-27.

Lawlor, Timothy E.
1976. Coat color adaptations of rodents occurring on lava beds — reanalysis of an exceptional case. J. Mammal. 57(2):391-397.

Lawrence, George Edwin.
1950. The diving and feeding activity of the western grebe on the breeding grounds. Condor 52(1):3-16.

Lawrence, Louise de Kiriline.
1948. Comparative study of the nesting behavior of chestnut-sided and Nashville warblers. Auk 65(2):204-219.

Lawrence, Louise de Kiriline.
1953. Nesting life and behavior of the red-eyed vireo. Can. Field-Nat. 67(2):47-77.

Lawrence, Louise de Kiriline.
1967. A comparative life-history study of four species of woodpeckers. Ornithol. Monogr. 5, 156 p. Am. Ornithol. Union, Anchorage, Ky.

Lechleitner, R. R.
1969. Wild mammals of Colorado: Their appearance, habits, distribution, and abundance. 254 p. Pruett Publ. Co., Boulder, Colo.

Lederer, Roger J.
1977a. Winter feeding territories in the Townsend's solitaire. Bird Banding 48(1):11-18.

Lederer, Roger J.
1977b. Winter territoriality and foraging behavior of the Townsend's solitaire. Am. Midl. Nat. 97(1):101-109.

Leege, Thomas A.
1968. Natural movements of beavers in southeastern Idaho. J. Wildl. Manage. 32(4):973-976.

Lemen, Cliff A., and Michael L. Rosenzweig.
1978. Microhabitat selection in two species of heteromyid rodents. Oecologia (Berl.) 33:127-135.

Lemon, R. E., and C. Chatfield.
1973. Organization of song of rose-breasted grosbeaks. Anim. Behav. 21:28-44.

Lenington, Sarah, and Terry Mace.
1975. Mate fidelity and nesting site tenacity in the killdeer. Auk 92(1):149-151.

Lewis, Robert A.
1975. Reproductive biology of the white-crowned sparrow. II. Environmental control of reproductive and associated cycles. Condor 77(2):111-124.

Licht, Lawrence E.
1975. Comparative life history features of the western spotted frog, *Rana pretiosa*, from low- and high-elevation populations. Can. J. Zool. 53(9):1254-1257.

Ligon, J. David.
1973. Foraging behavior of the white-headed woodpecker in Idaho. Auk 90(4):862-869.

Ligon, J. David, and Dennis J. Martin.
1974. Pinon seed assessment by the pinon jay, *Gymnorhinus cyanocephalus*. Anim. Behav. 22(2):421-429.

Lillywhite, Harvey B., Paul Licht, and Pamela Chelgren.
1973. The role of behavioral thermoregulation in the growth energetics of the toad, *Bufo boreas*. Ecology 54(2):375-383.

Lindsay, Stephen L., and Alfred E. Perry.
1977. An additional Merriam's shrew (*Sorex m. merriami*) specimen from Oregon. Murrelet 58(1):17.

Lindzey, Frederick B.
1978. Movement patterns of badgers in northwestern Utah. J. Wildl. Manage. 42(2):418-422.

Lingle, Gary R., and Thomas A. Schupbach.
1977. Food of a red-breasted merganser in Michigan. Jack-Pine Warbler 55:97.

Littlefield, Carroll D., and Eldon L. Mclaury.
1975. Ovenbird records for Oregon. West. Birds 6:114.

Lovell, B. B., M. G. Lindsay, J. A. Norgren, D. W. Anderson, and G. H. Simonson.
1969. Oregon's long-range requirements for water. General soil map report with irrigable areas. Owyhee Drainage Basin. Appendix 1-11. 72 p. Oreg. State Water Resour. Board, Salem.

Lunk, William A.
1962. The rough-winged swallow, *Stelgidopteryx ruficollis* (Vieillot): A study based on its breeding biology in Michigan. Nuttall Ornithol. Club Publ. 4, 155 p. Cambridge, Mass.

Luttich, Stuart, Donald H. Rusch, E. Charles Meslow, and Lloyd B. Keith.
1970. Ecology of red-tailed hawk predation in Alberta. Ecology 51(2):190-203.

Lyon, D. L.
1973. Territorial and feeding activity of broad-tailed hummingbirds (*Selasphorus platycercus*) in *Iris missouriensis*. Condor 75:346-349.

McAllister, Nancy Mahoney.
1955. Reproductive behavior of the eared grebe, *Podiceps caspicus nigricollis*. M.S. thesis. Univ. B.C., Vancouver. 68 p.

McAllister, Nancy Mahoney.
1963. Ontogeny of behaviour in five species of grebes. Ph. D. thesis. Univ. B.C., Vancouver. 135 p.

McCallum, D. Archibald, Walter D. Graul, and Ronald Zaccagnini.
1977. The breeding status of the long-billed curlew in Colorado. Auk 94(3):599-601.

McCarty, Richard.
1978. *Onychomys leucogaster*. Am. Soc. Mammal., Mammal. Species 87:1-6.

McClelland, Bernard Riley.
1975. Effectiveness of brown creeper's concealment behavior. West. Birds 6(1):24.

McClelland, Bernard Riley, and Sidney S. Frissell.
1975. Identifying forest snags useful for hole-nesting birds. J. For. 73(7):414-417.

McDaniel, V. Rick, and James E. Gardner.
1977. Cave fauna of Arkansas: Vertebrate taxa. Arkansas Acad. Sci. Proc. 31:68-71.

McDaniel, V. Rick, and Kenneth L. Smith.
1976. Cave fauna of Arkansas: Selected invertebrate taxa. Arkansas Acad. Sci. Proc. 30:57-60.

McGahan, Jerome.
1968. Ecology of the golden eagle. Auk 85(1):1-12.

McGilvrey, F. B., Compiler.
1968. Wood duck production habitat requirements. U.S. Dep. Inter., Bur. Sport Fish. and Wildl. Resour. Publ. 60, 32 p. Washington, D.C.

McGlinchy, S. E., R. A. Monson, and P. Nash, Compilers.
1971. An annotated bibliography of the wild sheep of North America. Rachelwood Wildl. Res. Preserve Publ. 1, 86 p.

McIntyre, Judy.
1978. The common loon: Part III: Population in Itasca State Park, Minnesota 1957-1976. Loon 50(1):38-44.

McIntyre, Judy W.
1975. Biology and behavior of the common loon (*Gavia immer*) with reference to its adaptability in a man-altered environment. Ph. D. thesis. Univ. Minn., Duluth. 230 p.

McKay, Donald O., and B. J. Verts.
1978. Estimates of some attributes of a population of Nuttall's cottontails. J. Wildl. Manage. 42(1):159-168.

McKee, Bates.
1972. Cascadia. The geologic evolution of the Pacific Northwest. 394 p. McGraw-Hill Book Co., New York.

McKinney, Theodore Duane.
1966. Survival, distribution, and reproduction of an introduced gray partridge population. M.S. thesis. Colo. State Univ., Fort Collins. 55 p.

McKnight, D. E.
1974. Dryland nesting by redheads and ruddy ducks. J. Wildl. Manage. 38(1):112-119.
McLaren, Peter Lorimer.
1975. Habitat selection and resource utilization in four species of wood warblers (Aves: Parulidae). Ph. D. thesis. Univ. Toronto, Toronto.
McLaren, William David.
1962. A preliminary study of nest site competition in a group of hole nesting birds. M.S. thesis. Univ. B.C., Vancouver. 57 p.
McNicholl, Martin Keli.
1971. The breeding biology and ecology of Forster's tern (*Sterna forsteri*) at Delta, Manitoba. .M.S. thesis. Univ. Manitoba, Winnipeg. 652 p.
McReynolds, H. E.
1976. Rare and endangered cave animals. *In* National cave management symposium proceedings, p. 38-42. Tom Aley and Doug Rhodes, eds. Speleobooks, Albuquerque, N.M.
Mace, Terrence R.
1978. Killdeer breeding densities. Wilson Bull. 90(3):442-443.
Mackie, Richard J., and Helmut K. Buechner.
1963. The reproductive cycle of the chukar. J. Wildl. Manage. 27(2):246-260.
Magistad, O. C.
1945. Plant growth relations on saline and alkaline soils. Bot. Rev. 11(4):181-230.
Manuwal, David A.
1970. Notes on the territoriality of Hammond's flycatcher (*Empidonax hammondi*) in western Montana. Condor 72(3):364-365.
Marcellini, Dale, and James P. Mackey.
1970. Habitat preferences of the lizards, *Sceloporus occidentalis* and *S. graciosus* (Lacertilia, Iguanidae). Herpetologica 26(1):51-56.
March, James Robert.
1967. Dominance relations and territorial behavior of captive shovelers, *Anas clypeata*. M.S. thesis. Univ. Minn., Minneapolis. 47 p.
Marshall, David B., and Harold F. Duebbert.
1965. Nesting of the ring-necked duck in Oregon in 1963 and 1964. Murrelet 46(3):43.
Marshall, Joe R., Jr.
1939. Territorial behavior of the flammulated screech owl. Condor 41(2):71-78.
Marti, Carl D.
1974. Feeding ecology of four sympatric owls. Condor 76(1):45-61.
Martin, Elwood M., and Samuel M. Carney.
1977. Population ecology of the mallard. IV. A review of duck hunting regulations, activity, and success with special reference to the mallard. U.S. Dep. Inter., Fish and Wildl. Serv. Resour. Publ. 130, 137 p.
Martin, Fant W.
1964. Behavior and survival of Canada geese in Utah. Utah Dep. Fish and Game Bull. 64(7):1-89.
Martin, Stephen G.
1970. The agonistic behavior of varied thrushes (*Ixoreus naevius*) in winter assemblages. Condor 72(4):452-459.
Martin, Stephen G.
1974. Adaptations for polygynous breeding in the bobolink, *Dolichonyx oryzivorus*. Am. Zool. 14(1):109-119.
Maser, Chris.
1975. Predation by common ravens on feral rock doves. Wilson Bull. 87(4):552-553.
Maser, Chris, E. Wayne Hammer, and Stanley H. Anderson.
1970. Comparative food habits of three owl species in central Oregon. Murrelet 51(3):29-33.
Maser, Chris, E. Wayne Hammer, and Stanley H. Anderson.
1971. Food habits of the burrowing owl in central Oregon. Northwest Sci. 45(1):19-26.
Maser, Chris, E. Wayne Hammer, Cheri Brown, Robert E. Lewis, Robert L. Rausch, and Murray L. Johnson.
1974. The sage vole, *Lagurus curtatus* (Cope 1868), in the Crooked River National Grassland, Jefferson County, Oregon. A contribution to its life history and ecology. Säugetierkd. Mitt. 22(3):193-222.
Maser, Chris, and Gerald S. Strickler.
1978. The sage vole, *Lagurus curtatus*, as an inhabitant of subalpine sheep fescue, *Festuca ovina*, communities on Steens Mountain — an observation and interpretation. Northwest Sci. 52(3):276-284.

Mason, Edwin A.
1953. Barn swallow life history data based on banding records. Bird Banding 24(3):91-100.
Mathisen, John E., David J. Sorenson, L. D. Frenzel, and Thomas C. Dunstan.
1977. Management strategy for bald eagles. Trans. North Am. Wildl. and Nat. Resour. Conf. 42:86-92.
Mathwig, Herbert J.
1973. Food and population characteristics of Iowa coyotes. Iowa State J. Res. 47(3):167-189.
Mayhew, W. W.
1965. Adaptations of the amphibian, *Scaphiopus couchi*, to desert conditions. Am. Midl. Nat. 74:95-109.
Mayhew, Wilbur W.
1958. The biology of the cliff swallow in California. Condor 60:7-37.
Melquist, Wayne E., Donald R. Johnson, and W. Dean Carrier.
1978. Migration patterns of northern Idaho and eastern Washington ospreys. Bird Banding 49(3):234-236.
Mendall, Howard L.
1958. The ring-necked duck in the Northeast. Univ. Maine Bull. 60(16), 2d Ser. 73, 317 p. Orono.
Meng, Heinz K.
1952. The Cooper's hawk, *Accipiter cooperii* (Bonaparte). Ph. D. thesis. Cornell Univ., Ithaca, N.Y. 136 p.
Meredith, Don H.
1976. Habitat selection by two parapatric species of chipmunks (*Eutamias*). Can. J. Zool. 54(4):536-543.
Mewaldt, L. Richard.
1956. Nesting behavior of the Clark nutcracker. Condor 58(1):3-23.
Meyerriecks, A. J.
1960. Comparative breeding behavior of 4 species of North American herons. Nuttall Ornithol. Club Publ. 2:1-158.
Michael, Chas. W.
1936. Nesting of the Williamson sapsucker. Condor 37(4):209-210.
Michener, Gail R.
1977. Effect of climatic condition on the annual activity and hibernation cycle of Richardson's ground squirrels and Columbian ground squirrels. Can. J. Zool. 55:693-703.
Michener, Gail R., and Daniel R. Michener.
1977. Population structure and dispersal in Richardson's ground squirrels. Ecology 58(2):359-368.
Michot, Thomas Claud.
1976. Nesting ecology of the redhead duck on Knudson Marsh, Utah. M.S. thesis. Utah State Univ., Logan. 62 p.
Mickelson, P. G.
1975. Breeding biology of cackling geese and associated species on the Yukon-Kuskokwim Delta, Alaska. Wildl. Monogr. 45, 35 p.
Miles, A. Keith.
1976. Fall migration of mourning doves in the western management unit. M.S. thesis. Oreg. State Univ., Corvallis. 85 p.
Miller, Alden H.
1939. Status of the breeding Lincoln's sparrows of Oregon. Auk 56(3):342-343.
Miller, Alden H., and T. T. McCabe.
1935. Racial differentiation in *Passerella (Melospiza) lincolnii*. Condor 37(3):144-160.
Miller, Don E., and John T. Emlen.
1975. Individual chick recognition and family integrity in the ring-necked gull. Behaviour 52(1-2):124-144.
Miller, Linda Jean.
1978. The spatial and temporal dispersion of nests as an adaptation to food exploitation and nest predation in the American goldfinch. Ph. D. thesis. Univ. Ill., Urbana-Champaign. 102 p.
Miller, Steven W., and John S. Barclay.
1974. Predation in warm water reservoirs by wintering common mergansers. *In* Proceedings of the 27th annual conference of the Southeastern Association of Game and Fish Commissioners, Oct. 14-17, 1973, Hot Springs, Arkansas, p. 243-252. [Columbia, S.C.]

Mills, Richard S., Gary W. Barrett, and Michael P. Farrell.
1975. Population dynamics of the big brown bat (*Eptesicus fuscus*) in southwestern Ohio. J. Mammal. 56(3):591-604.
Misterek, David Lloyd.
1974. The breeding ecology of the ruddy duck (*Oxyura jamaicensis*) on Rush Lake, Winnebago County, Wisconsin. M.S. thesis. Univ. Wis., Oshkosh. 82 p.
Mohr, Charles E.
1976. The protection of threatened cave bats. *In* National cave management symposium proceedings, p. 57-62. Tom Aley and Doug Rhodes, eds. Speleobooks, Albuquerque, N.M.
Moisan, Gaston.
1966. The green-winged teal: Its distribution, migration, and population dynamics. Ph. D. thesis. Laval Univ., Quebec. 354 p.
Moldenhauer, Ralph R.
1970. The effects of temperature on the metabolic rate and evaporative water loss of the sage sparrow, *Amphispiza belli nevadensis*. Comp. Biochem. Physiol. 36(3):579-587.
Moldenhauer, Ralph R., and John A. Wiens.
1970. The water economy of the sage sparrow, *Amphispiza belli nevadensis*. Condor 72(3):265-275.
Molini, William A.
1976. Chukar partridge species management plan. 51 p. Nev. Dep. Fish and Game.
Montevecchi, W. A.
1978. Corvids using objects to displace gulls from nests. Condor 80(3):349.
Montevecchi, William A.
1976. Egg size and the egg predatory behavior of crows. Behavior 57(3-4):307-320.
Morehouse, E. L., and R. Brewer.
1968. Feeding of nestling and fledgling kingbirds. Auk 85(1):44-54.
Morse, Douglass H.
1972. Habitat differences of Swainson's and hermit thrushes. Wilson Bull. 84(2):206-208.
Morse, Douglass H.
1973. The foraging of small populations of yellow warblers and American redstarts. Ecology 54(2):346-355.
Morse, Thomas E., Joel L. Jakabosky, and Vernon P. McCrow.
1969. Some aspects of the breeding biology of the hooded merganser. J. Wildl. Manage. 33(3):596-604.
Morton, Martin L., and John S. Gallup.
1975. Reproductive cycle of the Belding ground squirrel (*Spermophilus beldingi beldingi*): Seasonal and age differences. Great Basin Nat. 35(4):427-433.
Morton, Martin L., Judith L. Horstmann, and Janet M. Osborn.
1972. Reproductive cycle and nesting success of the mountain white-crowned sparrow (*Zonotrichia leucophrys oriantha*) in the central Sierra Nevada. Condor 74(2):152-163.
Morton, Martin L., and Paul W. Sherman.
1978. Effects of a spring snowstorm on behavior, reproduction, and survival of Belding's ground squirrels. Can. J. Zool. 56(12):2578-2590.
Mosher, James A., and Clayton M. White.
1976. Directional exposure of golden eagle nests. Can. Field-Nat. 90:356-359.
Motts, Ward S.
1965. Hydrologic types of playas and closed valleys and some relations of hydrology to playa geology. *In* Geology, mineralogy, and hydrology of U.S. playas, p. 73-104. U.S. Air Force Cambridge Res. Labs., Environ. Res. Pap. 96 (AFCRL-65-266).
Moulton, John C., and Phillip V. Vanderschaegen.
1974. Bibliography of the ruffed grouse. 31 p. Wis. Dep. Nat. Resour., Madison.
Mullins, William H., and Elwood G. Bizeau.
1978. Summer foods of sandhill cranes in Idaho. Auk 95(1):175-178.
Munro, J. A.
1939. Studies of waterfowl in British Columbia: No. 9. Barrow's goldeneye. Trans. R. Can. Inst. 22(48):259-318.
Munro, J. A.
1942. Studies of waterfowl in British Columbia: Bufflehead. Can. J. Res. Sect. D. 20(6):133-160.
Murie, Jan O.
1971. Behavioral relationships between two sympatric voles (*Microtus*): Relevance to habitat segregation. J. Mammal. 52(1):181-186.

Murphy, Joseph R.
1977. Status of eagle populations in the Western United States. World Conf. Birds Prey 1:57-63.

Murphy, Joseph R., Franz J. Camenzind, Dwight G. Smith, and J. Bradford Weston.
1969. Nesting ecology of raptorial birds in central Utah. Brigham Young Univ. Sci. Bull., Biol. Ser. 10(4):1-36.

Murray, Keith F.
1965. Population changes during the 1957-1958 vole (*Microtus*) outbreak in California. Ecology 46(1-2):163-171.

Murton, R. K., C. F. B. Coombs, and R. J. P. Thearle.
1972. Ecological studies of the feral pigeon *Columbia livia* var. II. Flock behaviour and social organization. J. Appl. Ecol. 9(3):875-889.

Murton, R. K., R. J. P. Thearle, and C. F. B. Coombs.
1974. Ecological studies of the feral pigeon *Columbia livia* var. III. Reproduction and plumage polymorphism. J. Appl. Ecol. 11(3):841-854.

Myres, Miles Timothy.
1957. An introduction to the behavior of the goldeneyes: *Bucephala islandica* and *B. clangula* (class Aves: Family Anatidae). M.S. thesis. Univ. B.C., Vancouver. 254 p.

Neal, James T.
1965. Environmental setting and general surface characteristics of playas. *In* Geology, mineralogy, and hydrology of U.S. playas, p. 1-29. U.S. Air Force Cambridge Res. Labs., Environ. Res. Pap. 96 (AFCRL-65-266).

Neal, James T.
1968a. Playa surface changes at Harper Lake, California 1962-1967. *In* Playa surface morphology: Miscellaneous investigations, p. 5-30. U.S. Air Force Cambridge Res. Labs., Environ. Res. Pap. 283 (AFCRL-68-0133).

Neal, James T.
1969. Playa variation. *In* Arid lands in perspective, p. 13-44, Univ. Ariz. Press, Tucson.

Neal, Thomas J.
1968b. A comparison of two muskrat populations. Iowa State J. Sci. 43(2):193-210.

Nehls, H. B.
1972. Oregon great blue heron nesting sites. 36 p. Portland Audubon Soc., Portland, Oreg.

Nelson, Theodora.
1939. The biology of the spotted sandpiper, *Actitis macularia* (Linn.). Ph. D. thesis. Univ. Mich., Ann Arbor. 170 p.

Nethersole-Thompson, Desmond.
1966. The snow bunting. 316 p. Oliver and Boyd Ltd., London.

Nice, Margaret Morse.
1943. Studies in the life history of the song sparrow: II. The behavior of the song sparrow and other passerines. Trans. Linn. Soc. New York 6:1-328.

Nickell, W. P.
1951. Studies of habitats, territory, and nests of the eastern goldfinch. Auk 68:447-470.

Nickell, Walter P.
1966. The nesting of the black-crowned night heron and its associates. Jack-Pine Warbler 44(3):130-139.

Noon, Barry Richard.
1977. The ecology of an avian ground-foraging guild in eastern montane forests. Ph. D. thesis. State Univ. N.Y., Albany. 189 p.

Northcott, Tom H., Neil F. Payne, and Eugene Mercer.
1974. Dispersal of mink in insular Newfoundland. J. Mammal. 55(1):243-248.

Nowicki, Timothy.
1974. The census of screech owls (*Otus asio*) using tape-recorded calls. Jack-Pine Warbler 52(3):98-101.

Nuechterlein, G. L.
1975. Nesting ecology of western grebes on Delta Marsh, Manitoba. M.S. thesis. Colo. State Univ., Fort Collins. 105 p.

Odum, Eugene P.
1941a. Annual cycle of the black-capped chickadee - 1. Auk 58:314-333.

Odum, Eugene P.
1941b. Annual cycle of the black-capped chickadee - 2. Auk 58(4):518-535.

O'Farrell, Michael J., and Andrew R. Blaustein.
1974. *Microdipodops megacephalus*. Am. Soc. Mammal., Mammal. Species 46:1-3.

O'Farrell, Michael J., and Eugene H. Studier.
1973. Reproduction, growth, and development in *Myotis thysanodes* and *M. lucifugus* (Chiroptera: Vespertilionidae). Ecology 54(1):18-30.

O'Farrell, Michael J., and Eugene H. Studier.
1975. Population structure and emergence activity patterns in *Myotis thysanodes* and *M. lucifugus* (Chiroptera: Vespertilionidae) in northeastern New Mexico. Am. Midl. Nat. 93(2):368-376.

O'Farrell, Thomas P., Richard J. Olson, Richard O. Gilbert, and John D. Hedlund.
1975. A population of Great Basin pocket mice, *Perognathus parvus*, in the shrub-steppe of south-central Washington. Ecol. Monogr. 45(1):1-28.

Ogden, Verland T., and Maurice G. Hornocker.
1977. Nesting density and success of prairie falcons in southwestern Idaho. J. Wildl. Manage. 41(1):1-11.

Ohlendorf, Harry M.
1974. Competitive relationships among kingbirds (*Tyrannus*) in Trans-Pecos, Texas. Wilson Bull. 86(4):357-373.

Ohlendorf, Harry M.
1976. Comparative breeding ecology of phoebes in Trans-Pecos, Texas. Wilson Bull. 88(2):255-271.

Olendorff, Richard R.
1972. The large birds of prey of the Pawnee National Grassland: Nesting habits and productivity, 1969-1971. U.S. Int. Biol. Program, Grassland Biome Tech. Rep. 151, 59 p. Nat. Resour. Ecol. Lab., Colo. State Univ., Fort Collins.

Olendorff, Richard R., and John W. Stoddart, Jr.
1974. The potential for management of raptor populations in western grasslands. Raptor Res. Rep. 2:44-88.

Olsen, David W.
1977. A literature review of pheasant habitat requirements and improvement methods. Utah Div. Wildl. Resour. Publ. 77-7, 150 p.

Olson, David Peter.
1964. A study of canvasback and redhead breeding populations: Nesting habitats and productivity. Ph. D. thesis. Univ. Minn., Minneapolis. 106 p.

Olson, Sigurd T., and William H. Marshall.
1952. A common loon in Minnesota. Minn. Mus. Nat. Hist. Occas. Pap. 5, 76 p. Univ. Minn. Press, Minneapolis.

Oregon Department of Fish and Wildlife.
1977. Oregon's threatened or endangered wildlife. 13 p.

Ormiston, John H.
1966. Food habits, habitat, and movements of mountain quail in Idaho. M.S. thesis. Univ. Idaho, Moscow. 39 p.

Orr, Robert T.
1940. The rabbits of California. Calif. Acad. Sci. Occas. Pap. 19, 227 p.

Orr, Robert T.
1954. Natural history of the pallid bat, *Antrozous pallidus* (LeConte). Proc. Calif. Acad. Sci. 4th Ser. 28(4):165-246. San Francisco.

Otto, Bruce R., and Dana A. Hutchison.
1977. The geology of Jordan Craters, Malheur County, Oregon. Ore Bin 39(8):125-140.

Ouellet, Henri.
1970. Further observations on the food and predatory habits of the gray jay. Can. J. Zool. 48(2):327-330.

Pace, Ann E.
1974. Systematic and biological studies of the leopard frogs (*Rana pipiens* complex) of the United States. Univ. Mich. Misc. Publ. Mus. Zool. 148, 140 p. Ann Arbor.

Parker, Richard C.
1973. Prairies and people: A current look at prairie falcon management and status in Washington. Wash. Wildl. 25(3):18-23.

Parker, William S.
1974a. Home range, growth, and population density of *Uta stansburiana* in Arizona. J. Herpetol. 8(2):135-139.

Parker, William S.
1976. Population estimates, age structure, and denning habits of whipsnakes, *Masticophis t. taeniatus*, in a northern Utah *Atriplex-Sarcobatus* community. Herpetologica 32(1):53-57.

Parker, William S., and William S. Brown.
1974. Mortality and weight changes of Great Basin rattlesnakes (*Crotalus viridis*) at a hibernaculum in northern Utah. Herpetologica 30(3):234-239.

Parker, William S., and Eric R. Pianka.
1975. Comparative ecology of populations of the lizard *Uta stanburiana*. Copeia 1975(4):615-632.

Parker, William S., and Eric R. Pianka.
1976. Ecological observations on the leopard lizard (*Crotaphytus wislizeni*) in different parts of its range. Herpetologica 32:95-114.

Parker, William Skinner.
1974b. Comparative ecology of two colubrid snakes, *Masticophis t. taeniatus* (Hallowell) and *Pituophis melanoleucus deserticola* (Stejneger), in northern Utah. Ph. D. thesis. Univ. Utah, Salt Lake. 307 p.

Parkes, W. S.
1972. Ecological study of the western whiptail lizard, *Cnemidophorus tigris gracilis*, in Arizona. Herpetologica 28:360-369.

Parsons, David R.
1975. Time and energy budgets of a population of dippers (*Cinclus mexicanus*) during winter in the Cascade Range of Oregon. M.S. thesis. Oreg. State Univ., Corvallis. 29 p.

Patton, Robert Farmer.
1974. Ecological and behavioral relationships of the skunks of Trans-Pecos, Texas. Ph. D. thesis. Texas A & M Univ., College Station. 219 p.

Payne, R. B.
1976. The clutch size and numbers of eggs of brown-headed cowbirds: Effect of latitude and breeding season. Condor 78:123-129.

Peabody, Robert B., Judith A. Johnson, and Edmund D. Brodie, Jr.
1975. Intra-specific escape from ingestion of the rubber boa, *Charina bottae*. J. Herpetol. 9(2):237.

Pearson, Oliver P., Mary R. Koford, and Anita K. Pearson.
1952. Reproduction of the lump-nosed bat (*Corynorhinus rafinesquei*) in California. J. Mammal. 33(3):273-320.

Petersen, Arnold J.
1955. The breeding cycle in the bank swallow. Wilson Bull. 67(4):235-286.

Peterson, Roger Tory.
1961. A field guide to western birds: Field marks of all species found in North America west of the 100th meridian, with a section on the birds of the Hawaiian Islands. 2d ed. 366 p. Houghton Mifflin Co., Boston.

Pianka, E. R.
1970. Comparative autecology of the lizard *Cnemidophorus tigris* in different parts of its geographic range. Ecology 51(4):703-720.

Pianka, Eric R., and William S. Parker.
1975. Ecology of horned lizards: A review with special reference to *Phrynosoma platyrhinos*. Copeia 1975(1):141-162.

Pickwell, Gayle B.
1931. The prairie horned lark. Trans. Acad. Sci. St. Louis, vol. 27, 153 p.

Pinkowski, Benedict C.
1978. Foraging ecology and habitat utilization in the genus *Sialia*. USDA For. Serv. Symp., Nacogdoches, Texas, July 13, 1978, 26 p.

Pitelka, F. A.
1951a. Speciation and ecological distribution of American jays of the genus *Aphelocoma*. Condor 47:229-261.

Pitelka, F. A.
1951b. Ecologic overlap and interspecific strife in breeding populations of Anna and Allen hummingbirds. Ecology 32:641-661.

Pitelka, Frank A.
1959. Numbers, breeding schedule, and territoriality in pectoral sandpipers of northern Alaska. Condor 61(4):233-264.

Planck, Roy Jonathan.
1967. Nest site selection and nesting of the European starling (*Sturnus vulgaris* L.) in California. Ph. D. thesis. Univ. Calif., Davis. 124 p.

Platt, Dwight.
1956. Food of the crow, *Corvus brachyrhynchos* Brehm, in south-central Kansas. Univ. Kans. Mus. Nat. Hist. Publ. 8(8):477-498.

Platt, Joseph B.
1973. Habitat and time utilization of a pair of nesting sharp-shinned hawks (*Accipiter striatus* velox) — a telemetry study. M.S. thesis. Brigham Young Univ., Provo, Utah. 42 p.

Platt, Joseph B.
1976. Bald eagles wintering in a Utah desert. Am. Birds 30(4):783-788.
Pleasants, Barbara Yohai.
1977. Ecological factors affecting the breeding dispersion patterns of some North American orioles. (Icterus). Ph. D. thesis. Univ. Calif., Los Angeles. 93 p.
Pohl, H., and G. C. West.
1976. Latitudinal and population specific differences in timing of daily and seasonal functions in redpolls (*Acanthis flammea*). Oecologia 25:211-227.
Pohl, H., and G. C. West.
1978. Longitude specific difference in timing of seasonal functions in two northern populations of the common redpoll, *Carduelis flammea*. Ornis Fenn. 55(1):36-38.
Porter, David K., Mark K. Strong, J. Brent Giezentanner, and Ronald A. Ryder.
1975. Nest ecology, productivity, and growth of the loggerhead shrike on the shortgrass prairie. Southwest. Nat. 19(4):429-436.
Porter, Kenneth R., and Dean E. Hakanson.
1976. Toxicity of mine drainage to embryonic and larval boreal toads (Bufonidae: *Bufo boreas*). Copeia 1976(2):327-331.
Porter, Richard D., and Clayton M. White.
1973. The peregrine falcon in Utah, emphasizing ecology and competition with the prairie falcon. Brigham Young Univ. Sci. Bull. Biol. Ser. 18(1), 74 p. Provo, Utah.
Pospahala, Richard S., David R. Anderson, and Charles J. Henny.
1974. Population ecology of the mallard: II. Breeding habitat conditions, size of the breeding populations, and production indices. U.S. Dep. Inter., Bur. Sport Fish. and Wildl. Resour. Publ. 115, 73 p.
Poston, H. J.
1974. Home range and breeding biology of the shoveler. Can. Wildl. Serv. Rep. Ser. 25, 49 p. Ottawa.
Poulson, T. L., and D. C. Culver.
1969. Diversity in terrestrial cave communities. Ecology 50(1):153-158.
Poulson, T. L., and W. B. White.
1969. The cave environment. Science 165(3897):971-981.
Power, Harry W., III.
1966. Biology of the mountain bluebird in Montana. Condor 68(4):351-371.
Pratt, Helen M.
1970. Breeding biology of great blue herons and common egrets in central California. Condor 72(4):407-416.
Preston, F. W., and R. T. Norris.
1947. Nesting heights of breeding birds. Ecology 28(3):241-273.
Price, Frank E., and Carl E. Bock.
1973. Polygyny in the dipper. Condor 75(4):457-459.
Pulliam, H. Ronald, and Frank Enders.
1971. The feeding ecology of five sympatric finch species. Ecology 52(4):557-566.
Pulliam, Ronald H., and G. Scott Mills.
1977. The use of space by wintering sparrows. Ecology 58(6):1393-1399.
Purdue, James Richard.
1974. Adaptations of the snowy plover, *Charadrius alexandrinus*, to an inland salt plain. Ph. D. thesis. Univ. Okla., Norman. 82 p.
Quaintance, Charles W.
1944. California cuckoo collected in eastern Oregon. Condor 46(2):89-90.
Rahn, Hermann.
1942. The reproductive cycle of the prairie rattler. Copeia 1942(4):233-240.
Randall, Jan A.
1978. Behavioral mechanisms of habitat segregation between sympatric species of *Microtus*: Habitat preference and interspecific dominance. Behav. Ecol. Sociobiol. 3:187-202.
Rees, William Ernest.
1973. Comparative ecology of three sympatric sparrows of the genus *Zonotrichia*. Ph. D. thesis. Univ. Toronto, Toronto. 224 p.
Reeve, Wayne L.
1952. Taxonomy and distribution of the horned lizard genus *Phrynosoma*. Univ. Kans. Sci. Bull. Vol. 34, Part 2, No. 14, p. 817-960.

Reeves, Henry M., Compiler.
1975. A contribution to an annotated bibliography of North American cranes, rails, woodcock, snipe, doves, and pigeons. U.S. Dep. Inter. Fish and Wildl. Serv., Natl. Tech. Inf. Serv. Rep. PB-240-999, 527 p. [Off. Migratory Bird Manage., Laurel, Md.]

Renwald, J. David.
1977. Effect of fire on lark sparrow nesting densities. J. Range Manage. 30(4):283-285.

Reynolds, Richard T., and Howard M. Wight.
1978. Distribution, density, and productivity of *Accipiter* hawks breeding in Oregon. Wilson Bull. 90(2):182-196.

Reynolds, Richard Truman.
1978. Food and habitat partitioning in two groups of co-existing *Accipiter*. Ph. D. thesis. Oreg. State Univ., Corvallis. 116 p.

Reynolds, Timothy D., and Terrell D. Rich.
1978. Reproductive ecology of the sage thrasher (*Oreoscoptes montanus*) on the Snake River Plain in south-central Idaho. Auk 95(3):580-582.

Rich, Terrell D. G.
1978a. Cowbird parasitism of sage and Brewer's sparrows. Condor 80(3):348.

Rich, Terrell D. G.
1978b. Nest placement in sage thrashers. Wilson Bull. 90(2):303.

Robbins, Sam.
1974. The willow and alder flycatchers in Wisconsin: A preliminary description of summer range. Passenger Pigeon 36(4):147-152.

Robertson, R. J.
1972. Optimal niche space of the red-winged blackbird (*Agelaius phoeniceus*). I. Nesting success in marsh and upland habitat. Can. J. Zool. 50(2):247-263.

Robertson, R. L.
1976. Ruffed grouse habitat preferences and effects of livestock grazing on habitat utilization. M.S. thesis. Utah State Univ., Logan. 62 p.

Robinson, T. W.
1958. Phreatophytes. U.S. Geol. Surv. Water-Supply Pap. 1423, p. 1-84. Washington, D.C.

Rofritz, David J.
1977. *Oligochaeta* as a winter food source for the oldsquaw. J. Wildl. Manage. 41(3):590-591.

Rogers, John Patrick.
1962. The ecological effect of drought on reproduction of the lesser scaup, *Aythya affinia* (Eyton). Ph. D. diss. Univ. Mo., Columbia. 109 p.

Rose, Barbara R.
1976. Habitat and prey selection of *Sceloporus occidentalis* and *Sceloporus graciosus*. Ecology 57(3):531-541.

Roth, Janet L.
1977. Breeding biology of the Nashville warbler in northern Michigan. Jack-Pine Warbler 55(3):129-141.

Rudolph, Seri G.
1978. Predation ecology of coexisting great horned and barn owls. Wilson Bull. 90(1):134-137.

Ruffer, David G.
1965. Burrows and burrowing behavior of *Onychomys leucogaster*. J. Mammal. 46(2):241-247.

Ruibal, Rudolfo.
1962. The ecology and genetics of a desert population of *Rana pipiens*. Copeia 1962(1):189-195.

Rundquist, Vaughn Marlan.
1973. Avian ecology on stock ponds in two vegetational types in north-central Montana. Ph. D. thesis. Mont. State Univ., Bozeman. 125 p.

Ruos, James L., and David D. Dolton, Compilers.
1977. Mourning dove status report, 1975. Spec. Sci. Rep., Wildl. 207, 27 p.

Rusch, Donald H., E. Charles Meslow, Phillip D. Doerr, and Lloyd B. Keith.
1972. Response of great horned owl populations to changing prey densities. J. Wildl. Manage. 36(2):282-296.

Russell, Henry N., Jr., and Angus M. Woodbury.
1941. Nesting of the gray flycatcher. Auk 58(1):28-37.

Russell, Israel C.
1903. Geology of southwestern Idaho and southeastern Oregon. U.S. Dep. Inter. Geol. Surv. Bull. 217, Ser. B, Descr. Geol. 32:7-83.

Rust, Henry Judson.
1947. Migration and nesting of nighthawks in northern Idaho. Condor 5(49):177-188.
Rutherford, W. H.
1964. The beaver in Colorado: Its biology, ecology, management and economics. Colo. Dep. Game, Fish, and Parks Tech. Bull. 17, 49 p.
Rutter, Russell J.
1969. A contribution to the biology of the gray jay (*Perisoreus canadensis*). Can Field-Nat. 83(4):300-316.
Ryder, John P.
1972. Biology of nesting Ross's geese. Ardea 60(3-4):185-215.
Ryder, John Pemberton.
1967a. The breeding biology of Ross' goose in the Perry River region, Northwest Territories. Can. Wildl. Serv. Rep. Ser. 3, 56 p. Can. Wildl. Serv., Ottawa.
Ryder, Ronald A.
1967b. Distribution, migration, and mortality of the white-faced ibis (*Pledgadis chihi*) in North America. Bird Banding 38(4):257-277.
Sabine, Winifred S.
1959. The winter society of the Oregon junco: Intolerance, dominance, and the pecking order. Condor 61(2):110-135.
Sadler, Douglas A. R., and W. J. Maher.
1976. Notes on the long-billed curlew in Saskatchewan. Auk 93(2):382-384.
Salt, George W., and Daniel E. Willard.
1971. The hunting behavior and success of Forster's tern. Ecology 52(6):989-998.
Samson, Fred B.
1976. Territory, breeding density, and fall departure in Cassin's finch. Auk 93:477-497.
Sargeant, Alan B., and Dwain W. Warner.
1972. Movements and denning habits of a badger. J. Mammal. 53(1):207-210.
Sather, J. Henry.
1958. Biology of the Great Plains muskrat in Nebraska. Wildl. Monogr. 2, 35 p.
Saul, Scott, Mark Swisher, Cliff Oakley, and others.
[1977.] A survey of bat populations and their habitat preferences in southern Oregon. A student-oriented studies project funded by Natl. Sci. Found. through South. Oreg. State Coll., Ashland. 89 p.
Schaefer, V. H.
1976. Geographic variations in the placement and structure of oriole nests. Condor 78:443-448.
Scheffer, Theo. H.
1938. Pocket mice of Washington and Oregon in relation to agriculture. U.S. Dep. Agric. Tech. Bull. 608, 16 p. Washington, D.C.
Schmidt, Karl Patterson, and D. Dwight Davis.
1941. Field book of snakes of the United States and Canada. 365 p. G. P. Putnam's Sons, New York.
Schneider, Dean G., L. David Mech, and John R. Tester.
1971. Movements of female raccoons and their young as determined by radio tracking. Anim. Behav. Monogr. 4 (part 1), 43 p.
Schnell, Gary D.
1968. Differential habitat utilization by wintering rough-legged and red-tailed hawks. Condor 70(4):373-377.
Scott, Dafila.
1977. Breeding behavior of wild whistling swans. Wildfowl 28:101-106.
Scott, J. Michael, Thomas W. Haislip, Jr., and Margaret Thompson.
1972. A bibliography of Oregon ornithology (1935-1970), with a cross-referenced list of the birds of Oregon. Northwest Sci. 46(2):122-139.
Sealy, Spencer G.
1978a. Litter size and nursery sites of the hoary bat near Delta, Manitoba. Blue Jay 36(1):51-52.
Sealy, Spencer G.
1978b. Clutch size and nest placement of the pied-billed grebe in Manitoba. Wilson Bull. 90(2):301-302.
Sebetich, Michael John.
1969. Spatial distribution, movement, and growth of the bullfrog, *Rana catesbeiana* Shaw. M.A. thesis. Coll. William and Mary, Williamsburg, Va. 75 p.
Seibert, Donald J., Robert J. Oakleaf, J. Michael Laughlin, and Jerry L. Page.
1976. Nesting ecology of golden eagles in Elko County, Nevada. U.S. Dep. Inter., Bur. Land Manage. Tech. Note 281, 17 p. Denver, Colo.

Seidensticker, John C., IV., Maurice G. Hornocker, Wilbur V. Wiles, and John P. Messick.
1973. Mountain lion social organization in the Idaho primitive area. Wildl. Monogr. 35, 60 p.

Selander, Robert K.
1954. A systematic review of the booming nighthawks of western North America. Condor 56(2):57-82.

Serie, J. R., and G. A. Swanson.
1976. Feeding ecology of breeding gadwalls on saline wetlands. J. Wildl. Manage. 40(1):69-81.

Severaid, Joye Harold.
1950. The pigmy rabbit (*Sylvilagus idahoensis*) in Mono County, California. J. Mammal. 31(1):1-4.

Severson, Keith E.
1978. A bibliography of blue grouse - 1889-1977. USDA For. Serv. Gen. Tech. Rep. RM-59, 10 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Shaw, William T.
1921. Moisture and altitude as factors in determining the seasonal activities of the Townsend ground squirrel in Washington. Ecology 2(3):189-192.

Shay, Ron.
1973. Oregon's rare or endangered wildlife. Oreg. State Game Comm. Bull., Jan., p. 3-8. Portland.

Sheldon, William G.
1949. Reproductive behavior of foxes in New York State. J. Mammal. 30(3):236-246.

Sheppard, David Henry.
1965. Ecology of the chipmunks, *Eutamias amoenus luteiventris* (Allen) and *E. minimus oreocetes* Merriam. Ph. D. thesis. Univ. Saskatchewan, Saskatoon. 255 p.

Sheridan, David.
1978. Dirt motorbikes and dune buggies threaten deserts. Smithsonian 9(6):66-75.

Sherwood, Glen A.
1960. The whistling swan in the West with particular reference to Great Salt Lake Valley, Utah. Condor 62(5):370-377.

Shump, Ann U., Karl A. Shump, Jr., Gary A. Heidt, and Richard J. Aulerich.
1976a. A bibliography of mustelids, Part II: Mink. Mich. Agric. Exp. Stn. 7390, 156 p. Mich. State Univ., East Lansing.

Shump, Karl A., Jr., Ann U. Shump, Richard J. Aulerich, and Gary A. Heidt.
1976b. A bibliography of mustelids, Part V: Otters. Mich. Agric. Exp. Stn. 7759, 32 p. Mich. State Univ., East Lansing.

Shump, Karl A., Jr., Ann U. Shump, Thomas W. Nelson, Gary A. Heidt, and Richard J. Aulerich.
1975. A bibliography of mustelids, Part III: Skunks. Mich. Agric. Exp. Stn. 7472, 34 p. Mich. State Univ., East Lansing.

Siegfried, W. Roy.
1977. Notes on behavior of ruddy ducks during the brood period. Wildfowl 28:126-128.

Simpson, Marcus B., Jr.
1978. Breeding season distribution and ecology of the vesper sparrow in the southern Blue Ridge Mountain province. Chat 42(1):1-2.

Sitton, Larry W.
1977. California mountain lion investigations with recommendations for management. 35 p. Rep. Calif. Dep. Fish and Game, Resour. Agency.

Skryja, David D.
1974. Reproductive biology of the least chipmunk (*Eutamias minimus operarius*) in southeastern Wyoming. J. Mammal. 55(1):221-224.

Sloan, Norman F.
1973. Status of breeding colonies of white pelicans in the United States through 1972. Inland Bird Banding News 45:20-28.

Smith, D. G., and C. D. Marti.
1976. Distributional status and ecology of barn owls in Utah. Raptor Res. 10:33-44.

Smith, Dwight G., and Charles R. Wilson.
1971. Notes on the winter food of screech owls in central Utah. Great Basin Nat. 31(2):83-84.

Smith, Dwight G., Charles R. Wilson, and Herbert H. Frost.
1972. The biology of the American kestrel in central Utah. Southwest. Nat. 17(1):73-83.

Smith, Dwight G., Charles R. Wilson, and Herbert H. Frost.
1974. History and ecology of a colony of barn owls in Utah. Condor 76(2):131-136.

Smith, Graham W.
1977. Population characteristics of the porcupine in northwestern Oregon. J. Mammal. 58(4):674-676.
Smith, R. I.
1970. Response of pintail breeding populations to drought. J. Wildl. Manage. 34(4):943-946.
Smith, Robert Leo.
1963. Some ecological notes on the grasshopper sparrow. Wilson Bull. 75(2):159-165.
Smith, Susan M.
1973a. A study of prey-attack behaviour in young loggerhead shrikes, *Lanius ludovicianus* L. Behaviour 44(1-2):113-141.
Smith, Susan M.
1973b. An aggressive display and related behavior in the loggerhead shrike. Auk 90(2):287-298.
Snow, Carol.
1972. Habitat management series for endangered species: American peregrine falcon, *Falco peregrinus anatum*, and arctic peregrine falcon, *Falco peregrinus tundrius*. U.S. Dep. Inter., Bur. Land Manage. Tech. Note 167, Rep. 1, 35 p. Denver, Colo.
Snow, Carol.
1973a. Habitat management series for unique or endangered species: Golden eagle, *Aquila chrysaetos*. U.S. Dep. Inter., Bur. Land Manage. Tech. Note 239, Rep. 7, 52 p. Denver, Colo.
Snow, Carol.
1973b. Habitat management series for endangered species: Southern bald eagle, *Haliaeetus leucocephalus leucocephalus*, and northern bald eagle, *Haliaeetus leucocephalus alascanus*. U.S. Dep. Inter., Bur. Land Manage. Tech. Note 171, Rep. 5, 58 p., Denver, Colo.
Snow, Carol.
1973c. Habitat management series for endangered species: San Joaquin kit fox, *Vulpes macrotis mutica*. Related subspecies and the swift fox, *Vulpes velox*. U.S. Dep. Inter., Bur. Land Manage. Tech. Note 238, Rep. 6, 24 p. Denver, Colo.
Snow, Carol.
1974a. Habitat management series for unique or endangered species: Prairie falcon, *Falco mexicanus*. U.S. Dep. Inter., Bur. Land Manage. Tech. Note 240, Rep. 8, 18 p. Denver, Colo.
Snow, Carol.
1974b. Habitat management series for endangered species: Spotted bat, *Euderma maculatum*. U.S. Dep. Inter., Bur. Land Manage. Tech. Note 170, Rep. 4, 13 p. Denver, Colo.
Snyder, C. T., D. G. Frickel, R. F. Hadley, and R. F. Miller.
1976. Effects of off-road vehicle use on the hydrology and landscape of arid environments in central and southern California. Water-Resour. Invest. 76-99, 45 p. U.S. Geol. Surv., Water Resour. Div., Denver, Colo.
Solomonson, Michael G., and Russell P. Balda.
1977. Winter territoriality of Townsend's solitaires (*Myadestes townsendi*) in pinyon-juniper-ponderosa pine ecotone. Condor 79(2):148-161.
Sonnenberg, E. L., and L. R. Powers.
1976. Notes on the food habits of long-eared owls (*Asio otus*) in southwestern Idaho. Murrelet 57(3):63-64.
Southern, William E.
1958. Nesting of the red-eyed vireo in the Douglas Lake Region, Michigan. Jack-Pine Warbler 36:105-130.
Spahn, Robert.
1978. Red-necked grebe invasion. Kingbird 28(2):95-96.
Spalding, D. J., and H. B. Mitchell.
1970. Abundance and distribution of California bighorn sheep in North America. J. Wildl. Manage. 34(2):473-475.
Spencer, Howard E., Jr.
1953. The cinnamon teal (*Anas cyanoptera* Viellot) its life history, ecology, and management. M.S. thesis. Utah State Agric. Coll., Logan. 184 p.
Springer, Alan M.
1975. Observations on the summer diet of rough-legged hawks from Alaska. Condor 77(3):338-339.
Staebler, Arthur Eugene.
1949. A comparative life history study of the downy and hairy woodpeckers (*Dendrocopos pubescens* and *Dendrocopos villosus*). Ph. D. diss. Univ. Mich., Ann Arbor. 234 p.
Staedeli, Jerry H.
1964. Eggs and young of the vermillion-lined ground snake, *Sonora semiannulata linearis*. Copeia 1964(3):581-582.

Stallcup, Patrick L.
1968. Spatio-thermal relationships of nuthatches and woodpeckers in ponderosa pine forests of Colorado. Ecology 49(5):831-834.
Stanley, William C.
1963. Habits of the red fox in northeastern Kansas. Univ. Kans. Mus. Nat. Hist. Misc. Publ. 34, 31 p.
Stebbins, Robert C.
1966. A field guide to western reptiles and amphibians: Field marks of all species in western North America. 279 p. Houghton, Mifflin Co., Boston.
Stebbins, Robert Cyril.
1951. Amphibians of western North America. 539 p. Univ. Calif. Press, Berkeley.
Stebbins, Robert Cyril.
1954. Amphibians and reptiles of western North America. 528 p. McGraw-Hill Book Co., Inc., New York.
Steenhoff, Karen.
1978. Management of wintering bald eagles. FWS/OBS-78/79. 59 p. U.S. Fish and Wildl. Serv., Washington, D.C.
Stenger, Judith.
1958. Food habits and available food of ovenbirds in relation to territory size. Auk 75:335-346.
Stenger, W. J.
1965. Territorial behavior of the tree sparrow. Condor 67:193-209.
Stepney, Philip H. R.
1975. Wintering distribution of Brewer's blackbird: Historical aspect, recent changes, and fluctuations. Bird Banding 46(2):106-125.
Stewart, P. A.
1969. Movements, population fluctuations, and mortality among great horned owl populations. Wilson Bull. 81(2):155-162.
Stewart, Paul A.
1952. Dispersal, breeding behavior, and longevity of banded barn owls in North America. Auk 69(3):227-245.
Stewart, Paul A.
1977. Migratory movements and mortality rate of turkey vultures. Bird Banding 48(2):122-124.
Stewart, R. E.
1953. A life history study of the yellowthroat. Wilson Bull. 65:99-115.
Stewart, Robert M., R. Phillip Henderson, and Kate Darling.
1977. Breeding ecology of the Wilson's warbler in the High Sierra Nevada, California. Living Bird 16:83-102.
Stickel, William H.
1943. The Mexican snakes of the genera *Sonora* and *Chionactis* with notes on the status of other Colubrid genera. Biol. Soc. Wash. Proc. 56(1943):109-128.
Stiles, F. G.
1971. Time, energy, and territoriality of the Anna hummingbird (*Calypte anna*). Science 173:818-821.
Stiles, F. G., and L. L. Wolf.
1973. Food supply and the annual cycle of the Anna hummingbird. Univ. Calif. Publ. Zool. 97:1-109.
Stoner, Dayton.
1936. Studies on the bank swallow, *Riparia riparia riparia* (Linnaeus), in the Oneida Lake region. Roosevelt Wild Life Ann. 4(2):126-233. Roosevelt Wild Life For. Exp. Stn., N.Y. State Coll. For. Syracuse Univ., Syracuse.
Stones, Robert C., and C. Lynn Hayward.
1968. Natural history of the desert woodrat, *Neotoma lepida*. Am. Midl. Nat. 80:458-476.
Storer, Robert W., W. Roy Siegfried, and John Kinahan.
1976. Sunbathing in grebes. Living Bird 14:45-57.
Storer, T. I., F. P. Cronemiller, E. E. Horn, and Ben Glading.
1942. Studies on valley quail. Calif. Agric. Stn. Bull. 663, p. 130-135.
Storey, A. E.
1977. Adaptations for marsh nesting on common terns (*Sterna hirundo*) and Forster's terns (*S. forsteri*). Abstr. Am. Zool. 17(4):891.
Storm, Gerald L., Ronald D. Andrews, Robert L. Phillips, Richard A. Bishop, Donald B. Siniff, and John R. Tester.
1976. Morphology, reproduction, dispersal, and mortality of midwestern red fox populations. Wildl. Monogr. 49, 82 p.
Storm, Robert M.
1966. Endangered plants and animals of Oregon. II. Amphibians and reptiles. Oreg. State Univ. Agric. Exp. Stn., Spec. Rep. 206, 3 p. Corvallis.

Stout, G. D., Ed.
1967. The shorebirds of North America. 270 p. Viking Press, New York.

Stull, Olive Griffith.
1940. Variations and relationships in the snakes of the genus *Pituophis*. U.S. Nat. Mus. Bull. 175, 225 p. Washington, D.C.

Sturman, William A.
1968. Description and analysis of breeding habitats of the chickadees, *Parus atricapillus* and *P. rufescens*. Ecology 49(3):418-431.

Sugden, Lawson G.
1977. Horned grebe breeding habitat in Saskatchewan parklands. Can. Field.-Nat. 91(4):372-376.

Sugden, Lawson G.
1978. Canvasback habitat use and production in Saskatchewan parklands. Can. Wildl. Serv. Occas. Pap. 34, 32 p.

Summers-Smith, James Denis.
1967. An annotated bibliography of the genus *Passer*. Int. Stud. Sparrows 1(2):3-82.

Summers-Smith, James Denis, and J. Pinkowski.
1968. An annotated bibliography of the genus *Passer*. II. Int. Stud. Sparrows 2(2):43-75.

Sumner, E. Lowell, Jr.
1935. A life history study of the California quail, with recommendations for its conservation and management. Calif. Fish and Game 21(3):167-256.

Sundstrom, Charles, William G. Hepworth, and Kenneth L. Diem.
1973. Abundance, distribution and food habits of the pronghorn. Wyo. Game and Fish Comm. Bull. 12, 61 p. Cheyenne.

Swanson, George A., and Mavis I. Meyer.
1977. Impact of fluctuating water levels on feeding ecology of breeding blue-winged teal. J. Wildl. Manage. 41(3):426-433.

Swanson, George A., Mavis I. Meyer, and Jerome R. Serie.
1974. Feeding ecology of breeding blue-winged teals. J. Wildl. Manage. 38(3):396-407.

Sweeney, Steve.
1977. Survey of native cats of Washington. Wash. Game Dep. Job Completion Rep., Proj. W-84-R, Study II and III, Job 1, 55 p. Olympia.

Tabor, J. E., and H. M. Wight.
1977. Population status of river otter in western Oregon. J. Wildl. Manage. 41(4):692-699.

Tanner, Wilmer W., and John E. Krogh.
1973. Ecology of *Phrynosoma platyrhinos* at the Nevada test site, Nye County, Nevada. Herpetologica 29(4):327-342.

Tanner, Wilmer W., and John E. Krogh.
1974. Ecology of the leopard lizard, *Crotaphytus wislizeni*, at the Nevada test site, Nye County, Nevada. Herpetologica 30(1):63-72.

Terry, Carol J.
1978. Food habits of three sympatric species of Insectivora in western Washington. Can. Field-Nat. 92(1):38-44.

Tevis, Lloyd, Jr.
1952. Autumn foods of chipmunks and golden-mantled ground squirrels in the northern Sierra Nevada. J. Mammal. 33(2):198-205.

Thompson, Bruce C.
1977. Behavior of Vaux's swifts nesting and roosting in a chimney. Murrelet 58(3):73-77.

Thompson, C. F., and V. Nolan, Jr.
1973. Population biology of the yellow-breasted chat (*Icteria virens* L.) in southern Indiana. Ecol. Monogr. 43:145-171.

Thompson, W. L.
1960. Agonistic behavior in the house finch. Part I: Annual cycle and display patterns. Condor 62:245-271.

Thompson, William L.
1976. Vocalizations of the lazuli bunting. Condor 78(2):195-207.

Thornton, W. A.
1960. Population dynamics in *Bufo woodhousei* and *Bufo valliceps*. Tex. J. Sci. 12(3-4):176-200.

Thut, Rudolph N.
1970. Feeding habits of the dipper in southwestern Washington. Condor 72(2):234-235.

Tinbergen, N.
1935. Field observations of east Greenland birds: I. The behavior of the red-necked phalarope (*Phalaropus lobatus* L.) in spring. Ardea 24:1-42.

Tinbergen, N.
1939. The behavior of the snow bunting in spring. Trans. Linn. Soc. N.Y. 5:1-94.
Tinkle, Donald W.
1967. The life and demography of the side-blotched lizard, *Uta stansburiana*. Univ. Mich. Mus. Zool. Misc. Publ. 132, 182 p. Ann Arbor.
Tinkle, Donald W.
1973. A population analysis of the sagebrush lizard, *Sceloporus graciosus* in southern Utah. Copeia 1973(2):284-296.
Tomback, Diana Francine.
1977. The behavioral ecology of the Clark's nutcracker (*Nucifraga columbiana*) in the eastern Sierra Nevada. Ph. D. thesis. Univ. Calif., Santa Barbara. 223 p.
Tompa, Frank S.
1962. Territorial behavior: The main controlling factor of a local song sparrow population. Auk 79(4):687-697.
Tousley, Richard S.
1976. National Park System objectives and philosophies of cave management. *In* National cave management symposium proceedings, p. 142-143. Tom Aley and Doug Rhodes, eds. Speleobooks, Albuquerque, N.M.
Toweill, Dale E.
1974. Winter food habits of river otters in western Oregon. J. Wildl. Manage. 38(1):107-111.
Trimble, Stephen A.
1975a. Habitat management series for unique or endangered species: Merlin *Falco columbarius*. U.S. Dep. Inter., Bur. Land Manage. Tech. Note 271, Rep. 15, 41 p. Denver, Colo.
Trimble, Steve.
1975b. Non-game birds of the West: An annotated bibliography; the ecology and life histories of seven orders. U.S. Dep. Inter., Bur. Land Manage. Tech. Note 269, 320 p. Denver, Colo.
Tuck, Leslie M.
1972. The snipes: A study of the genus *Capella*. Can. Wildl. Serv. Monogr. Ser. 5, 429 p. Ottawa.
Turcek, Frantisek J., and Leon Kelso.
1968. Ecological aspects of food transportation and storage in the Corvidae. Commun. Behav. Biol., Part A, 1:277-297.
Turner, Frederick B.
1960. Population structure and dynamics of the western spotted frog, *Rana p. pretiosa* Baird and Girard, in Yellowstone Park, Wyoming. Ecol. Monogr. 30(3):251-278.
Turner, Larry W.
1972. Habitat differences between *Spermophilus beldingi* and *Spermophilus columbianus* in Oregon. J. Mammal. 53(4):914-917.
Tuttle, Merlin D., and Lawrence R. Heaney.
1974. Maternity habits of *Myotis leibii* in South Dakota. South. Calif. Acad. Sci. Bull. 73(2):80-83. Los Angeles.
U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife.
1973. Threatened wildlife of the United States. Resour. Publ. 114, 289 p. Off. Endangered Species and Int. Act., Washington, D.C.
U.S. Department of the Interior, Fish and Wildlife Service.
1962. Abstracts of mourning dove literature. U.S. Fish and Wildl. Serv. Circ. 136, 153 p. Washington, D.C.
Urban, David.
1970. Raccoon populations, movement patterns, and predation on a managed waterfowl marsh. J. Wildl. Manage. 34(2):372-382.
VanCamp, Laurel F., and Charles J. Henny.
1975. The screech owl: Its life history and population ecology in northern Ohio. U.S. Dep. Inter. Fish and Wildl. Serv., North Am. Fauna 71, 65 p. Washington, D.C.
Van Tets, Gerrard Frederick.
1959. A comparative study of the reproductive behavior and natural history of three sympatric species of cormorants, *Phalacrocorax auritus*, *P. penicillatus*, and *P. pelagicus*. M.A. zool. thesis. Univ. B.C., Vancouver. 86 p.
Verbeek, Nicolaas A. M.
1967. Breeding biology and ecology of the horned lark in alpine tundra. Wilson Bull. 79(2):208-218.
Verbeek, Nicolaas A. M.
1970. Breeding ecology of the water pipit. Auk 87(3):425-451.

Vermeer, K.
1970. Breeding biology of California and ring-billed gulls: A study of ecological adaptations to the inland habitat. Can. Wildl. Serv. Rep. Ser. 12, 52 p.
Verner, J.
1963. Aspects of the ecology and evolution of the long-billed marsh wren. Ph. D. thesis. Univ. Wash., Seattle. 149 p.
Verner, Jared.
1975. Complex song repertoire of male long-billed marsh wrens in eastern Washington. Living Bird, 14th Annu. 1975, p. 263-300. Cornell Lab. Ornithol., New York.
Verner, Jared, and Gay H. Engelsen.
1970. Territories, multiple nest building, and polygyny in the long-billed marsh wren. Auk 87(3):557-567.
Verner, Jared, and Mary F. Wilson.
1969. Mating systems, sexual dimorphism, and the role of male North American passerine birds in the nesting cycle. Ornithol. Monogr. 9, 76 p. Am. Ornithol. Union.
Verts, B. J.
1967. The biology of the striped skunk. 218 p. Univ. Ill. Press, Urbana.
Verts, B. J.
1975. New records for three uncommon mammals in Oregon. Murrelet 56(3):22-23.
Vitt, Laurie J., and Robert D. Ohmart.
1977. Ecology and reproduction of lower Colorado River lizards: II. *Cnemidophorus tigris* (Teiidae) with comparisons. Herpetologica 33(2):223-234.
Wakeley, James S.
1974. Activity periods, hunting methods and efficiency of the ferruginous hawk. Raptor Res. 8(3-4):72-76.
Walker, George W.
1977. Geologic map of Oregon east of the 121st meridian. Misc. Invest. Ser., May I-092, 2 p. U.S. Dep. Inter., U.S. Geol. Surv., Reston, Va.
Walkinshaw, Lawrence H.
1949. The sandhill cranes. Cranbrook Inst. Sci. Bull. 29, 202 p. Bloomfield Hills, Mich.
Wallestad, Richard.
1975. Life history and habitat requirements of sage grouse in central Montana. 66 p. Mont. Dep. Fish and Game, Game Manage. Div., Helena.
Wasserman, A. O.
1958. Relationships of allopatric populations of spadefoots (genus *Scaphiopus*). Evolution 11:311-319.
Weber, David, Barry Barnes, and Jessop B. Low.
1974. The blue grouse in northern Utah. Utah Sci. 35(2):43-46.
Weber, Wayne C.
1975. Occurrence and possible breeding of the white-throated swift at Spences Bridge, British Columbia. Murrelet 56(2):10-11.
Weeden, J. Stenger.
1958. Territorial behavior of the tree sparrow. Condor 67(3):193-209.
Weigand, John Paul.
1977. The biology and ecology of the Hungarian (European grey) partridge (*Perdix perdix* L.) in north-central Montana. Ph. D. thesis. Mont. State Univ., Bozeman. 408 p.
Weller, M. W.
1961. Breeding biology of the least bittern. Wilson Bull. 73(1):11-25.
Weller, M. W.
1964. Distribution and migration of the redhead. J. Wildl. Manage. 28(1):64-103.
Wells, P. V.
1958. Indigo buntings in lazuli bunting habitat in southwestern Utah. Auk 75:223-224.
Welsh, Daniel A.
1975. Savannah sparrow breeding and territoriality on a Nova Scotia dune beach. Auk 92(2):235-251.
Westerskov, Kaj E.
1949. A comparative study of the ecology and management of the European partridge, *Perdix p. perdix*, in Ohio and Denmark. M.S. thesis. Ohio State Univ., Columbus. 339 p.
Weston, John Bradford.
1969. Nesting ecology of the ferruginous hawk, *Buteo regalis*. Brigham Young Univ. Sci. Bull. Biol. Ser. 10(4):25-36.
Wetmore, A.
1925. Food of American phalaropes, avocets, and stilts. U.S. Dep. Agric. Dep. Bull. 1359, 20 p.
Wheeler, Richard J.
1965. Pioneering of blue-winged teal in California, Oregon, Washington, and British Columbia. Murrelet 46(3):40-42.

Whitaker, Gene A.
1974. Phoebe and barn swallow nesting structures. 31st Northeast. Fish and Wildl. Conf. Trans., p. 57-62. Northeast. Sect. Wildl. Soc. [USDA Conserv. Serv., College Park, Md.]

Whitaker, John O., Jr., and Chris Maser.
1976. Food habits of five western Oregon shrews. Northwest Sci. 50(2):102-107.

Whitaker, John O., Jr., Chris Maser, and Laurel E. Keller.
1977. Food habits of bats of western Oregon. Northwest Sci. 51(1):46-55.

Whitaker, John O., Jr., and Russell E. Mumford.
1972. Ecological studies on *Reithrodontomys megalotis* in Indiana. J. Mammal. 53(4):850-860.

Whitford, Walter G.
1976. Temporal fluctuations in density and diversity of desert rodent populations. J. Mammal. 57(2):351-369.

Whitmore, Robert C.
1975. Indigo buntings in Utah with special reference to interspecific competition with lazuli buntings. Condor 77(4):509-510.

Wiens, John A.
1973. Interterritorial habitat variation in grasshopper and savannah sparrows. Ecology 54(4):877-884.

Wiewandt, Thomas A.
1969. Vocalization, aggressive behavior, and territoriality in the bullfrog, *Rana catesbeiana*. Copeia 1969(2):276-285.

Wildlife Management Institute.
1966. Wood duck management and research: A symposium. 212 p. Washington, D.C.

Williamson, Penelope.
1971. Feeding ecology of the red-eyed vireo. (*Vireo olivaceus*) and associated foliage-gleaning birds. Ecol. Monogr. 41(2):129-152.

Willner, Gale R., Joseph A. Chapman, and James R. Goldsberry.
1975. A study and review of muskrat food habits with special reference to Maryland. Maryland Wildl. Adm. Publ. Wildl. Ecol. 1, 25 p. [Md. Dep. Nat. Resour., LaVale.]

Willson, Mary F.
1966. Breeding ecology of the yellow-headed blackbird. Ecol. Monogr. 36(1):51-77.

Willson, Mary F., and Gordon H. Orians.
1963. Comparative ecology of red-winged and yellow-headed blackbirds during the breeding season. 16th Congr. Zool. Proc. 3:342-346.

Winegardner, S. C.
1976. Ecology of the common snipe in northern Utah. M.S. thesis. Utah State Univ., Logan. 76 p.

Winter, Jon.
1974. The distribution of the flammulated owl in California. West. Birds 5(2):25-44.

Wirtz, William O., II., and Paul G. Pearson.
1960. A preliminary analysis of habitat orientation in *Microtus* and *Peromyscus*. Am. Midl. Nat. 63(1):131-142.

Wolffinden, Neil D.
1975. Ecology of the ferruginous hawk (*Buteo regalis*) in central Utah: Population dynamics and nest site selection. Ph. D. thesis. Brigham Young Univ., Provo, Utah. 102 p.

Wolford, J. W., and D. A. Boag.
1971. Distribution and biology of black-crowned night herons in Alberta. Can. Field-Nat. 85(1):13-19.

Woodbury, Marian, and Angus M. Woodbury.
1945. Life-history studies of the sagebrush lizard *Sceloporus g. graciosus* with special reference to cycles in reproduction. Herpetologica 2(7-8):175-196.

Woods, John G.
1972. An introduction to the literature on the saw-whet owl. Ont. Bird-Banding 8(1):8-23.

Wright, Albert Hazen, and Anna (Allen) Wright.
1949. Handbook of frogs and toads of the United States and Canada. 640 p. Comstock Publ. Co., Inc., Ithaca, N.Y.

Wright, Albert Hazen, and Anna (Allen) Wright.
1957. Handbook of snakes of the United States and Canada. 2 vols. 1,105 p. Comstock Publ. Assoc., Cornell Univ. Press, Ithaca, N.Y.

Wunderle, Joseph M., Jr.
1978. Differential response of territorial yellowthroats to the songs of neighbors and non-neighbors. Auk 95(2):389-395.

Yoakum, Jim.
1967. Literature of the American pronghorn antelope: An annotated bibliography with abstracts emphasizing food habits and range relationships. 82 p. U.S. Dep. Inter., Bur. Land Manage. Reno, Nev.

Yousef, M. K., and W. G. Bradley.
1971. Physiological and ecological studies on *Citellus lateralis*. Comp. Biochem. and Physiol. 39(4A):671-682.

Zach, Reto.
[In press.] Foraging and territoriality of male ovenbirds (Aves: Parulidae) in a heterogenous habitat. J. Anim. Ecol.

Zarn, Mark.
1974a. Habitat management series for unique or endangered species: Osprey, *Pandion haliaetus carolinensis*. U.S. Dep. Inter., Bur. Land Manage. Tech. Note 254, Rep. 12, 41 p. Denver, Colo.

Zarn, Mark.
1974b. Habitat management series for unique or endangered species: Burrowing owl, *Speotyto cunicularia hypugaea*. U.S. Dep. Inter., Bur. Land Manage. Tech. Note 250, Rep. 11, 25 p. Denver, Colo.

Zegers, David A.
1976. Population dynamics of Richardson's ground squirrel, *Spermophilus richardsonii elegans*, in a montane meadow system. Abstr. J. Colo. Acad. Sci. 8(1):67-68.

Appendix 1

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Appendix 2

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Appendix 1

Generalized Response of Terrestrial Species of Vertebrate Wildlife to Geomorphic and Edaphic Habitats

Legend: r = reproduction o = other (cover, travel, observation, etc.) CAPITALS = "essential habitat" for the species
f = feeding x = use

WILDLIFE SPECIES	FEATURES					CLIFFS																
						STRUCTURAL CHARACTERISTICS																
						Height class				Length class					Joint spacing (between joints)					Joint width (opening)				
	Caves	Rock shelters	Loose slabs	Ledges	Fissures	3 m	3–10 m	10–30 m	30 m	<30 m	30–100 m	100–500 m	500–1 500 m	>1 500 m	30 m	7.5–30 m	1.5–7.5 m	0.3–1.5 m	0.3 m	<0.15 m	0.15–0.30 m	0.3–0.6 m	0.6–1.5 m	>1.5 m
Common name																								
Amphibians																								
long-toed salamander					fo	x	x	x	x											fo				
Great Basin spadefoot																								
western toad	fo	fo	fo			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Woodhouse toad	fo	fo	fo			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Pacific tree frog	fo	fo	fo			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
spotted frog																								
leopard frog																								
bullfrog																								
Reptiles																								
collared lizard			rfo		rfo	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
leopard lizard																								
western fence lizard	rfo	rfo	rfo	fo	rfo	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
sagebrush lizard																								
side-blotched lizard	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
desert horned lizard																								
short-horned lizard																								
western skink																								
western whiptail																								
rubber boa						x	x	x	x	x	x	x	x	x										
yellow-bellied racer		fo	fo	fo	fo	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
striped whipsnake		fo	fo	fo	fo	x	x	x	x	x	x	x	x	x										
gopher snake																								
common garter snake			fo																					
wandering garter snake			fo																					
western ground snake	rfo	rfo	rfo			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
night snake	rfo	rfo	rfo			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
western rattlesnake	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Birds																								
common loon																								
red-necked grebe																								
horned grebe																								
eared grebe																								
western grebe																								
pied-billed grebe																								
American white pelican									o					o										
double-crested cormorant				RO			RO	RO	RO			RO	RO	RO										
great blue heron				o																				
green heron																								
cattle egret				o																				
common egret				o																				
black-crowned night heron																								
American bittern																								
least bittern																								
white-faced ibis																								
whistling swan																								
Canada goose				r			r	r	r	r	r	r	r	r										
white-fronted goose																								
snow goose																								
Ross' goose																								
mallard			r	ro	r	ro	ro	ro	ro	ro	ro	ro	ro	ro	r	r	r	r	r		r	r	r	r
gadwall							o	o				o	o	o										
common pintail							o	o				o	o	o										
green-winged teal							o	o				o	o	o										
blue-winged teal							o	o				o	o	o										
cinnamon teal							o	o				o	o	o										
American wigeon							o	o				o	o	o										
northern shoveler							o	o				o	o	o										
wood duck							o	o				o	o	o										
redhead							o	o				o	o	o										
ring-necked duck							o	o				o	o	o										
canvasback							o	o				o	o	o										
greater scaup							o	o				o	o	o										
lesser scaup							o	o				o	o	o										
common goldeneye							o	o				o	o	o										

ASSOCIATIONS	CAVES									TALUS									LAVA FLOWS		SAND DUNES		PLAYAS		EDAPHIC HABITATS
Proximity to water	TYPES				CHARACTERISTICS: Opening size (diameter)			CHARACTERISTICS: Depth (horizontal)		TYPES					CLASSES, by size of rock (diameter)										
<0.4 km	>0.4 km	Shallow caves	Cliff-face caves	Lava tubes	Mine shafts	<0.3 m	0.3–1 m	>1 m	<10 dm	10–30 dm	>30 dm	Cliff talus	Lava stringers	Collapsed lava tubes	Mine tailings	Roadside talus	I	II	III	IV	Old	New	Stabilized	Active	Alkaline	Fresh	
FO												fo	fo	fo	to	to	x	x	x							RF	
												fo	fo	fo	to	fo	x	x	x							RFO	
FO		fo		fo	fo	x	x	x	x	x	x	fo	fo	fo	to	fo	x	x	x	x						RF	
FO		fo		fo	fo	x	x	x	x	x	x	fo	fo	fo	to	fo	x	x	x	x						RF	
FO		fo		fo	fo	x	x	x	x	x	x	fo	fo	fo	fo	fo	x	x	x	x						RF	
																										RFO	
FO												fo	fo	fo	fo	fo	x	x	x								
x	x											RFO	RFO	RFO	RFO	RFO	X	X	X	X	X				fo	fo	rfo
x	x	rfo				x			x			rfo	rfo	rfo	rfo	rfo	x	x	x	x	rfo	rfo					
												rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x				fo
x	x	rfo	rfo	rfo	rfo	x	x	x	x			rfo	rfo	rfo	rfo	rfo	x	x	x	x	x						
																							rfo	x			
																							rfo	x			
												rfo	rfo	rfo	rfo	rfo	x	x	x	x			rfo				
												rfo	rfo	rfo	rfo	rfo	x	x	x	x			rfo	x			x
X												rfo	rfo		rfo	rfo	x	x	x	x							
x	x	fo	fo	fo	fo	x	x	x	x			RFO	RFO	RFO	RFO	RFO		X	X	X							x
x	x											rfo	rfo	rfo	x	x		x	x	x							
		fo				x	x	x	x			rfo	rfo	rfo	rfo	rfo	x	x	x	x							
X												rfo	rfo	rfo	rfo	rfo	x	x	x					x			
X	X	to	fo	fo	fo	x	x	x	x			rfo	rfo	rfo	rfo	rfo	x	x	x					x			
x	x											RFO	RFO				X	X	X	X							
x	x											rfo	rfo	rfo	rfo	rfo	x	x	x	x							
x	x	rfo		rfo	rfo	x	x	x	x			RFO	RFO	RFO	RFO	RFO	X	X	X	X							
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R																									o		
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Appendix 1 (continued)

Generalized Response of Terrestrial Species of Vertebrate Wildlife to Geomorphic and Edaphic Habitats

Legend: r = reproduction o = other (cover, travel, observation, etc.) CAPITALS = "essential habitat" for the species
f = feeding x = use

WILDLIFE SPECIES	FEATURES					CLIFFS																			
						STRUCTURAL CHARACTERISTICS																			
						Height class				Length class					Joint spacing (between joints)					Joint width (opening)				
	Caves	Rock shelters	Loose slabs	Ledges	Fissures	<3 m	3–10 m	10–30 m	>30 m	<30 m	30–100 m	100–500 m	500–1 500 m	>1 500 m	>30 m	7.5–30 m	1.5–7.5 m	0.3–1.5 m	<0.3 m	<0.15 m	0.15–0.30 m	0.3–0.6 m	0.6–1.5 m	>1.5 m
Barrow's goldeneye								o	o			o	o	o										
bufflehead								o	o			o	o	o										
oldsquaw								o	o			o	o	o										
King eider								o	o			o	o	o										
ruddy duck								o	o			o	o	o										
hooded merganser								o	o			o	o	o										
common merganser			ro	ro	ro	ro	ro	ro	ro	ro	ro	ro	ro	ro							ro	ro	ro
red-breasted merganser								o	o			o	o	o										
turkey vulture	RO	FO		RO		FO	FO	R	R	X	X	X	X	X										
northern goshawk		f		f		f	f	f	f	f	f	f	f	f										
sharp-shinned hawk		f		f		f	f	f	f	f	f	f	f	f										
Cooper's hawk		f		f		f	f	f	f	f	f	f	f	f										
red-tailed hawk				rfo				r	r	rfo	rfo	rfo	rfo	rfo										
Swainson's hawk				fo		fo	fo	fo	fo	fo	fo	fo	fo	fo										
rough-legged hawk				fo		fo	fo	fo	fo	fo	fo	fo	fo	fo										
ferruginous hawk			rfo	RFO		RFO	RFO	RFO	RFO	RFO	RFO	RFO	RFO	RFO										
golden eagle				RFO				RFO	RFO	RFO	RFO	RFO	RFO	RFO										
bald eagle				fo				fo	fo	fo	fo	fo	fo	fo										
northern harrier						fo	fo	fo	fo	fo	fo	fo	fo	fo										
osprey				ro				ro	ro		ro	ro	ro	ro										
prairie falcon		RFO		RFO				RFO	RFO	RFO	RFO	RFO	RFO	RFO										
peregrine		RFO		RFO					RF	RFO	RFO	RFO	RFO	RFO										
merlin				rfo				rfo	rfo	rfo	rfo	rfo	rfo	rfo										
American kestrel			rfo		RFO		rfo	rfo	rfo	rfo	rfo	rfo	rfo	rfo	r	r	r	r	r			r		
blue grouse						f	f	f	f	f	f	f	f	f										
ruffed grouse																								
sage-grouse						fo	fo	fo		fo	fo	fo	fo											
California quail			ro	fo	o	rfo	rfo	rfo	rfo	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x	x	x	x
mountain quail			rfo	rfo	rfo	rfo	rfo	rfo	rfo	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x	x	x	x
chukar		RFO	RFO	RFO	RFO	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x
gray partridge				f		fo	fo			fo	fo	fo	fo	fo										
ring-necked pheasant				f		fo	fo			fo	fo	fo	fo	fo										
sandhill crane																								
Virginia rail																								
sora																								
American coot			ro			x	x			x	x	x	x	x										
snowy plover								o	o			o	o	o										
killdeer								o	o			o	o	o										
mountain plover								o	o			o	o	o										
common snipe								o	o			o	o	o										
long-billed curlew				fo		x	x	x	x	x	x	x	x	x										
semi-palmated plover								o	o			o	o	o										
spotted sandpiper								o	o			o	o	o										
solitary sandpiper								o	o			o	o	o										
greater yellowlegs								o	o			o	o	o										
lesser yellowlegs								o	o			o	o	o										
willet								o	o			o	o	o										
pectoral sandpiper								o	o			o	o	o										
Baird's sandpiper				fo	fo			fo	fo			fo	fo	fo										
least sandpiper								o	o			o	o	o										
western sandpiper				fo	fo			fo	fo			fo	fo	fo										
long-billed dowitcher								o	o			o	o	o										
marbled godwit								o	o			o	o	o										
American avocet								o	o			o	o	o										
black-necked stilt								o	o			o	o	o										
Wilson's phalarope								o	o			o	o	o										
northern phalarope								o	o			o	o	o										
herring gull								o	o			o	o	o										
California gull								o	o			o	o	o										
ring-billed gull								o	o			o	o	o										
Franklin's gull								o	o			o	o	o										
Bonaparte's gull								o	o			o	o	o										
Forster's tern								o	o			o	o	o										
Caspian tern								o	o			o	o	o										
black tern								o	o			o	o	o										
rock dove		RFO	RFO	RFO	RFO		RFO	RFO	RFO	RFO	RFO	RFO	RFO	RFO										
mourning dove								o	o			o	o	o										
yellow-billed cuckoo			fo	fo	fo	x	x			x	x	x	x											
barn owl	RFO	RFO	RFO	RFO	RFO		RFO	RFO	RFO	rfo	rfo	rfo	rfo	rfo								r	r	r

ASSOCIATIONS		CAVES									TALUS									LAVA FLOWS		SAND DUNES		PLAYAS		EDAPHIC HABITATS
Proximity to water		TYPES				CHARACTERISTICS					TYPES					CLASSES, by size of rock (diameter)										
						Opening size (diameter)			Depth (horizontal)																	
<0.4 km	>0.4 km	Shallow caves	Cliff-face caves	Lava tubes	Mine shafts	< 0.3 m	0.3–1 m	>1 m	<10 dm	10–30 dm	>30 dm	Cliff talus	Lava stringers	Collapsed lava tubes	Mine tailings	Roadside talus	I	II	III	IV	Old	New	Stabilized	Active	Alkaline	Fresh	
o																										fo	
o																										fo	
o																										fo	
o																										fo	
o																										fo	
o																										fo	
ro																										fo	
o																										fo	
X	X											x	x	x	x	x	x	x	x	x							
x	x											x	x				x	x	x	x							
x	x											x	x				x	x	x	x							
x	x											x	x				x	x	x	x							
x	x											x	x	x	x	x	x	x	x	x							
fo	fo											f	f	f	f	f	x	x	x	x	fo	fo				fo	
fo	fo											f	f	f	f	f	x	x	x	x	fo	fo				fo	
x	x											rfo	rfo	rfo	rfo	rfo	x	x	x	x	rfo	rfo				fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x	fo	fo				fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x	fo	fo				fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x	fo	fo				fo	
x																										fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x	fo	fo				fo	
x	x											fo	to	fo	fo	fo	x	x	x	x	fo	fo				fo	
x	x																									to	
x	x											fo	fo	fo	fo	fo	x	x	x	x	fo	fo				fo	
x																											
												rfo					x	x	x	x							
x	x																x	x	x	x							
x												rfo	rfo	rfo			x	x	x	x							
x												RFO	RFO	RFO			X	X	X	X							
X												rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x					
x	x											fo	fo	fo	fo	fo	x	x	x	x			x				
x												rfo					x	x	x	x			x				
																										fo	
																										fo	
																										fo	
																										fo	
x												rfo					x	x	x	x							
x	x																								fo	fo	R
x																										rfo	fo
x	x																								fo	RFO	fo
x																										fo	
x	x																									fo	
x																										fo	
x																										fo	
x																										rfo	
x																										rfo	
x	x																									f

Appendix 1 (continued)

Generalized Response of Terrestrial Species of Vertebrate Wildlife to Geomorphic and Edaphic Habitats

Legend: r = reproduction o = other (cover, travel, observation, etc.) CAPITALS = "essential habitat" for the species
f = feeding x = use

WILDLIFE SPECIES	FEATURES					CLIFFS																
						STRUCTURAL CHARACTERISTICS																
						Height class				Length class					Joint spacing (between joints)					Joint width (opening)				
	Caves	Rock shelters	Loose slabs	Ledges	Fissures	<3 m	3–10 m	10–30 m	>30 m	30–100 m	100–500 m	500–1 500 m	>1 500 m	>30 m	7.5–30 m	1.5–7.5 m	0.3–1.5 m	<0.3 m	0.15–0.30 m	0.3–0.6 m	0.6–1.5 m	>1.5 m
common barn-owl	RFO	RFO	RFO	RFO	RFO		RFO	RFO	RFO	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		r	r	
flammulated owl			fo	fo	fo		fo	fo	fo	fo	fo	fo	fo	fo	x	x	x	x	x	x	x		
great horned owl	RFO	RFO	RFO	RFO	RFO		x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
pygmy owl		fo	fo	fo	fo		x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
burrowing owl		fo	fo	fo	fo	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
long-eared owl																							
short-eared owl																							
saw-whet owl		fo	fo	fo	fo		x	x	x	x	x	x	x	x	x	x	x	x			x	x	x
poorwill				rfo		x	x	x	x	x	x	x	x										
common nighthawk				rfo		x	x	x	x	x	x	x	x										
black swift				f	RO			X	X	X	X	X	X	x	x	x	x	x	x				
Vaux's swift				f	RO			X	X	X	X	X	X	x	x	x	x	x					
white-throated swift			RO	f	RO			X	X	X	X	X	X	x	x	x	x		x				
black-chinned hummingbird																							
Anna's hummingbird																							
broad-tailed hummingbird																							
rufous hummingbird																							
calliope hummingbird																							
belted kingfisher																							
common flicker			fo	fo			x	x	x	x	x	x	x										
Lewis' woodpecker			fo	fo			x	x	x	x	x	x	x										
yellow-bellied sapsucker																							
Williamson's sapsucker																							
hairy woodpecker																							
downy woodpecker																							
white-headed woodpecker																							
eastern kingbird			fo	fo	fo		x	x	x	x	x	x	x								x	x	x
western kingbird			rfo	rfo	rfo		x	x	x	x	x	x	x								x	x	x
ash-throated flycatcher				fo	fo		x	x	x	x	x	x	x										
Say's phoebe	RFO	RFO	RFO	RFO	RFO	x	x	x	x	x	x	x	x								x	x	x
willow flycatcher				fo	fo		x	x	x	x	x	x	x										
Hammond's flycatcher				fo	fo		x	x	x	x	x	x	x										
gray flycatcher				fo	fo		x	x	x	x	x	x	x										
western flycatcher				fo	fo		x	x	x	x	x	x	x										
western wood pewee			rfo	rfo	rfo		x	x	x	x	x	x	x										
olive-sided flycatcher				fo	fo		x	x	x	x	x	x	x										
horned lark		fo	fo	fo	fo	x	x	x	x	x	x	x	x					x	x	x	x	x	
violet-green swallow				fo			x	x	x	x	x	x	x										
tree swallow				fo			x	x	x	x	x	x	x										
bank swallow				fo			x	x	x	x	x	x	x										
rough-winged swallow				fo			x	x	x	x	x	x	x										
barn swallow		RFO	RFO	RFO	RFO			x	x	x	x	x	x								x	x	x
cliff swallow		RFO	RFO	RFO	RFO			x	x	x	x	x	x								x	x	x
gray jay																							
Stellar's jay																							
scrub jay				fo		x	x	x	x	x	x	x	x										
black-billed magpie		fo	fo	fo	fo	x	x	x	x	x	x	x	x									x	x
northern raven		RFO	RFO	RFO	RFO			x	x		x	x	x										x
American crow		fo	fo	fo	fo		x	x	x	x	x	x	x										x
pinyon jay		fo	fo	fo	fo		x	x	x														
Clark's nutcracker	fo	fo	fo	fo	fo		x	x	x		x	x	x	x									
black-capped chickadee		rfo	rfo	rfo	rfo		x	x	x	x	x	x	x	x				x	x	x	x	x	x
mountain chickadee		fo	fo	fo	fo		x	x	x	x	x	x	x	x				x	x	x	x	x	x
bushtit			fo	fo	fo	x	x	x	x	x	x	x	x	x				x	x	x	x	x	x
white-breasted nuthatch																							
red-breasted nuthatch																							
brown creeper																							
dipper				RO		x	x	x	x	x	x	x	x	x				x	x				
house wren		rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
winter wren		rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
marsh wren																							
canyon wren		RFO	RFO	RFO	RFO	x	x	x	x	x	x	x	x	x	x	x	x	x					
rock wren		fo	fo	fo	fo	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
gray catbird																							
brown thrasher																							
sage thrasher																							
American robin				o		x	x	x	x	x	x	x	x										
varied thrush				o		x	x	x	x	x	x	x	x										
hermit thrush			rfo	rfo	rfo	x	x	x	x	x	x	x	x										

ASSOCIATIONS		CAVES										TALUS										LAVA FLOWS		SAND DUNES		PLAYAS		EDAPHIC HABITATS
Proximity to water		TYPES				CHARACTERISTICS: Opening size (diameter)			CHARACTERISTICS: Depth (horizontal)			TYPES					CLASSES, by size of rock (diameter)											
<0.4 km	>0.4 km	Shallow caves	Cliff-face caves	Lava tubes	Mine shafts	<0.3 m	0.3–1 m	>1 m	<10 dm	10–30 dm	>30 dm	Cliff talus	Lava stringers	Collapsed lava tubes	Mine tailings	Roadside talus	I	II	III	IV	Old	New	Stabilized	Active	Alkaline	Fresh	
x	x	R	R	R	R	r			r	r		f	f	f	f	f	x	x	x	x	x		x			f	
x	x																											
x	x	RFO	RFO	RFO	RFO		x	x	x	x	x	f	f	f	f	f	x	x	x	x	f		f			f	
x	x	fo	fo	fo	fo	x	x	x	x	x	x	f	f	f	f	f	x	x	x	x	f		f			f	
x	x	fo	fo	fo	fo	x	x	x	x	x	x	fo	fo	fo	fo	fo	x	x	x	x	f		f			f	f
												fo	fo	fo	fo	fo	x	x	x	x	f		f			f	
												f	f	f	f	f	x	x	x	x			rfo			fo	
x	x	fo	fo	fo	fo	x	x	x	x	x	x	fo	fo	fo	fo	fo	x	x	x	x	f		f			fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x	f	f	f	f	f	f	f
x	x											fo	fo	fo	fo	fo	x	x	x	x	f	f	f	f	f	f	f
x	x											f	f	f	f	f	x	x	x	x	f	f	f	f	f	f	
x	x											f	f	f	f	f	x	x	x	x	f	f	f	f	f	f	
x	x		x			x			x	x		f	f	f	f	f	x	x	x	x	f	f	f	f	f	f	
x																					f		f			f	
x																					f		f			f	
x																					f		f			f	
x																					f		f			f	
x																					f		f			f	
x																					f		f			f	
x																					f		f			f	
x																											
x																					f		f			f	
x																					f		f			f	
												fo	fo	fo	to	fo	x	x	x	x	x		x			x	
x												fo	fo	fo	fo	fo	x	x	x	x	x		x			x	
x												fo					x	x	x	x	x		x			fo	
x	x	rfo	rfo	rfo	rfo		x	x	x	x	x																
x												fo					x	x	x	x	x		x			fo	
x												fo					x	x	x	x	x		x			fo	
x												to															
x												fo					x	x	x	x	x		x			fo	
x												fo					x	x	x	x	x		x			fo	
x												fo					x	x	x	x	x		x			fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x			fo	f
x												fo														f	
x												fo														f	
x												fo														f	
x												fo														f	
X	X											fo	fo	fo	fo	fo	x	x	x	x					FO	FO	
X	X											fo	fo	fo	fo	fo	x	x	x	x					FO	FO	
x												fo					x	x	x	x							
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x			f	
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x			f	
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x			f	
x												fo	fo	fo	fo	fo	x	x	x	x	x		x			fo	
x	x											f	f	f	f	f	x	x	x	x	x		x		f	f	
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x			f	
x												fo	fo	fo			x	x	x	x	x					fo	
x												fo	fo	fo			x	x	x	x	x					fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x		x	fo	
x												x					x	x	x	x							
x												rfo	rfo	rfo	rfo	rfo	x	x	x	x							
x												rfo	rfo	rfo	rfo	rfo	x	x	x	x						rfo	
x	x											x	x	x	x	x	x	x	x	x							
x	x											RFO	RFO	RFO	RFO	RFO	x	x	x	x							
x												fo	fo	fo	fo	fo	x	x	x	x							
x												fo	fo	fo	fo	fo	x	x	x	x	x		x				
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x			fo	
x																										fo	
x												rfo					x	x	x	x							

Appendix 1 (continued)

Generalized Response of Terrestrial Species of Vertebrate Wildlife to Geomorphic and Edaphic Habitats

Legend: r = reproduction o = other (cover, travel, observation, etc.) CAPITALS = "essential habitat" for the species
f = feeding x = use

WILDLIFE SPECIES	FEATURES					CLIFFS																				
						STRUCTURAL CHARACTERISTICS																				
						Height class				Length class					Joint spacing (between joints)					Joint width (opening)					
	Caves	Rock shelters	Loose slabs	Ledges	Fissures	1 m	3–10 m	10–30 m	>30 m	30 m	30–100 m	100–500 m	500–1 500 m	>1 500 m	>30 m	7.5–30 m	1.5–7.5 m	0.3–1.5 m	<0.3 m	<0.15 m	0.15–0.30 m	0.3–0.6 m	0.6–1.5 m	>1.5 m
Swainson's thrush			rfo	rfo	rfo	x	x	x	x	x	x	x	x	x											
western bluebird		rfo	rfo	rfo	rfo		x	x	x	x	x	x	x	x						x	x	x			
mountain bluebird		rfo	rfo	rfo	rfo		x	x	x	x	x	x	x	x						x	x	x			
Townsend's solitaire				fo		x	x	x	x	x	x	x	x	x											
blue-gray gnatcatcher				fo		x	x	x	x	x	x	x	x	x											
water pipit				fo			x	x	x	x	x	x	x	x											
Bohemian waxwing				o			x	x	x	x	x	x	x	x											
cedar waxwing				fo			x	x	x	x	x	x	x	x											
northern shrike			fo	fo	fo		x	x	x	x	x	x	x	x								x	x	x	
loggerhead shrike			fo	fo	fo		x	x	x	x	x	x	x	x								x	x	x	
European starling	rfo	rfo	rfo	rfo	rfo		x	x	x	x	x	x	x	x								x	x	x	
solitary vireo																									
red-eyed vireo																									
warbling vireo																									
orange-crowned warbler																									
yellow warbler																									
yellow-rumped warbler																									
black-throated gray warbler																									
Townsend's warbler																									
ovenbird																									
MacGillivray's warbler																									
common yellowthroat																									
yellow-breasted chat																									
Wilson's warbler																									
American redstart																									
house sparrow	fo	fo	fo	fo	fo		x	x	x	x	x	x	x	x											
bobolink																									
western meadowlark				fo		x	x	x	x	x	x	x	x	x											
yellow-headed blackbird				o		x	x	x	x	x	x	x	x	x											
red-winged blackbird				o		x	x	x	x	x	x	x	x	x											
northern oriole																									
Brewer's blackbird				o		x	x	x	x	x	x	x	x	x											
brown-headed cowbird				o		x	x	x	x	x	x	x	x	x											
western tanager																									
rose-breasted grosbeak																									
black-headed grosbeak																									
indigo bunting																									
lazuli bunting																									
evening grosbeak																									
purple finch																									
Cassin's finch																									
house finch	fo		fo	fo	fo		x	x	x	x	x	x	x	x											
common redpoll				fo		x	x	x	x	x	x	x	x	x											
pine siskin																									
American goldfinch				fo		x	x	x	x	x	x	x	x	x											
lesser goldfinch				fo		x	x	x	x	x	x	x	x	x											
green-tailed towhee		rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x
rufous-sided towhee		rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x
savannah sparrow				fo		x	x			x	x	x	x	x											
grasshopper sparrow				fo		x	x			x	x	x	x	x											
vesper sparrow				fo		x	x			x	x	x	x	x											
lark sparrow				fo		x	x	x	x	x	x	x	x	x											
sage sparrow				fo		x	x	x	x	x	x	x	x	x											
northern junco		rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
American tree sparrow		fo	fo	fo	fo	x	x	x	x	x	x	x	x	x											
chipping sparrow		rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Brewer's sparrow		fo	fo	fo		x	x	x	x	x	x	x	x	x											
white-crowned sparrow		fo	fo	fo		x	x	x	x	x	x	x	x	x											
golden-crowned sparrow		fo	fo	fo		x	x	x	x	x	x	x	x	x											
fox sparrow				fo		x	x	x	x	x	x	x	x	x											
Lincoln's sparrow				fo		x	x	x	x	x	x	x	x	x											
song sparrow		rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lapland longspur		fo		fo		x	x	x	x	x	x	x	x	x											
snow bunting		fo		fo		x	x	x	x	x	x	x	x	x											

ASSOCIATIONS		CAVES								TALUS										LAVA FLOWS		SAND DUNES		PLAYAS		EDAPHIC HABITATS
Proximity to water		TYPES				CHARACTERISTICS				TYPES					CLASSES, by size of rock (diameter)											
						Opening size (diameter)			Depth (horizontal)																	
<0.4 km	>0.4 km	Shallow caves	Cliff-face caves	Lava tubes	Mine shafts	<0.3 m	0.3–1 m	>1 m	<10 dm	10–30 dm	>30 dm	Cliff talus	Lava stringers	Collapsed lava tubes	Mine tailings	Roadside talus	I	II	III	IV	Old	New	Stabilized	Active	Alkaline	Fresh	
x												rfo					x	x	x	x							
x																										
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x			fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x			fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x			fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x							
x	x																									fo	
x	x																									fo	
x	x																									fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x			x			fo	
x	x																										
x		ro	ro			x			x	x																t	
																										fo	
																										fo	
																										fo	
																										fo	
x	x																				rfo		rfo			fo	
x																										fo	
x																										fo	
x																										fo	
x																										fo	
																										fo	
																										fo	
																										fo	
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																										fo	
																										fo	
																										fo	
																										fo	
r	o																									fo	
x	x																				x		x			x	
x																					t		f			fo	
x																					f		f			fo	
x	x											rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x			fo	
x												rfo	rfo	rfo	rfo	rfo	x	x	x	x							fo	
x	x											rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x				fo	
x	x											rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x				fo	
x	x											rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x				fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x				fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x				fo	
x												rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x				fo	
x												fo	fo	fo	fo	fo	x	x	x	x	x		x				fo	
x												rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x				fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x				fo	
x												fo	fo	fo	fo	fo	x	x	x	x	x		x				fo	
x												fo	fo	fo	fo	fo	x	x	x	x	x		x				fo	
x												fo	fo	fo	fo	fo	x	x	x	x	x		x				fo	
x												fo	fo	fo	fo	fo	x	x	x	x	x		x				fo	
x												rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x				fo	
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x				f	
x	x											fo	fo	fo	fo	fo	x	x	x	x	x		x				f	

Appendix 1 (continued)

Generalized Response of Terrestrial Species of Vertebrate Wildlife to Geomorphic and Edaphic Habitats

Legend: r = reproduction o = other (cover, travel, observation, etc.) CAPITALS = "essential habitat" for the species
f = feeding x = use

WILDLIFE SPECIES	FEATURES					CLIFFS																
						STRUCTURAL CHARACTERISTICS																
						Height class				Length class					Joint spacing (between joints)					Joint width (opening)				
	Caves	Rock shelters	Loose slabs	Ledges	Fissures	<3 m	3–10 m	10–30 m	>30 m	<30 m	30–100 m	100–500 m	500–1 500 m	>1 500 m	>30 m	7.5–30 m	1.5–7.5 m	0.3–1.5 m	<0.3 m	<0.15 m	0.15–0.30 m	0.3–0.6 m	0.6–1.5 m	>1.5 m
Mammals																								
Marbled shrew																								
wandering shrew																								
Merriam shrew																								
little brown myotis	RO	RO	RO	RO	RO		x	x	x	x	x	x	x	x	x	x	x	x	x					
Yuma myotis																								
long-eared myotis																								
fringed myotis																								
long-legged myotis																								
California myotis	RO	RO	RO		RO		x	x	x	x	x	x	x	x	x	x	x	x	x					
small-footed myotis	RO	RO	RO		RO		x	x	x	x	x	x	x	x	x	x	x	x	x					
silver-haired bat																								
western pipistrelle	RO	RO	RO		RO		x	x	x	x	x	x	x	x	x	x	x	x	x					
big brown bat	RO	RO	RO		RO		x	x	x	x	x	x	x	x	x	x	x	x	x					
hoary bat																								
spotted bat	RO	RO	RO		RO		x	x	x	x	x	x	x	x	x	x	x	x	x					
western big-eared bat	RO						x	x	x	x	x	x	x	x										
pallid bat	RO	RO	RO		RO		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
pygmy rabbit																								
mountain cottontail																								
white-tailed jackrabbit																								
black-tailed jackrabbit																								
least chipmunk	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
yellow-pine chipmunk	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
yellow-bellied marmot		RFO	RFO	RFO	RFO	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
antelope ground squirrel																								
Townsend ground squirrel																								
Richardson ground squirrel																								
Belding ground squirrel																								
mantled ground squirrel			RFO	RFO	RFO	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x		
Townsend pocket gopher																								
northern pocket gopher																								
little pocket mouse																								
Great Basin pocket mouse																								
dark kangaroo mouse																								
Ord kangaroo rat																								
chisel-toothed kangaroo rat																								
beaver																								
western harvest mouse		rfo	rfo		rfo	x	x	x	x	x	x	x	x	x					x					
canyon mouse	RFO	RFO	RFO	RFO	RFO		x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
deer mouse	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
northern grasshopper mouse																								
desert woodrat																								
bushy-tailed woodrat	RFO	RFO	RFO	RFO	RFO	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
montane vole																								
long-tailed vole																								
sage vole																								
muskrat																								
western jumping mouse																								
porcupine	rfo	rfo	rfo	rfo	rfo	x	x			x	x	x	x	x							x	x	x	
coyote	rfo	rfo	rfo			x	x	x	x	x	x	x	x	x							x	x	x	
red fox	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x							x	x	x	
kit fox	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x							x	x	x	
raccoon	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x							x	x	x	
long-tailed weasel	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x					x	x	x			
mink	rfo	rfo	rfo	rfo	rfo	x	x	x		x	x	x	x	x						x	x	x	x	x
badger	rfo	rfo	rfo			x	x	x	x	x	x	x	x	x							x	x	x	x
spotted skunk	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x						x	x	x	x	x
striped skunk	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x							x	x	x	x
river otter	rfo	rfo	rfo			x	x	x	x	x	x	x	x	x							x	x	x	x
cougar	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x								x	x	x
bobcat	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x							x	x	x	x
mule deer		o		f		x	x	x	x	x	x	x	x	x										
pronghorn																								
bighorn sheep	rfo	rfo		rfo			x	x	x	x	x	x	x	x										

ASSOCIATIONS		CAVES										TALUS										LAVA FLOWS		SAND DUNES		PLAYAS		EDAPHIC HABITATS
Proximity to water		TYPES				CHARACTERISTICS						TYPES					CLASSES, by size of rock (diameter)											
						Opening size (diameter)			Depth (horizontal)																			
<0.4 km	>0.4 km	Shallow caves	Cliff-face caves	Lava tubes	Mine shafts	<0.3 m	0.3–1 m	>1 m	<10 dm	10–30 dm	>30 dm	Cliff talus	Lava stringers	Collapsed lava tubes	Mine tailings	Roadside talus	I	II	III	IV	Old	New	Stabilized	Active	Alkaline	Fresh	
X		RO	RO	RO	RO	x	x	x	x	x	x	fo	fo	to	fo	fo	f	f	f		f	f				f	
X																											fo	
X																											lo	
X																											lo	
X																											fo	
X		RO	RO	RO	RO	x	x	x	x	x	x						f	f	f		f	f				f	
X		RO	RO	RO	RO	x	x	x	x	x	x	f	f	f	f	f	f	f	f	t	t	t				f	
X																											fo	
X		RO	RO	RO	RO	x	x	x	x	x	x	rfo	rfo	rfo	rfo	rfo	f	f	f	f	f	f				fo	
X		RO	RO	RO	RO	x	x	x	x	x	x	f	f	f	f	f	f	f	f	f	f	f				fo	
X																											fo	
X																											fo	
X			RO	RO		x	x	x		x	x	fo	fo	fo	fo	fo	f	f	f	f	f	f				fo	
X		RO	RO	RO		x	x	x		x	x	fo	fo	fo	fo	fo	f	f	f	f	f	f				fo	
x	x											rfo	rfo	rfo			x	x	x				RFO				
x												RFO	RFO	RFO	RFO	RFO	x	x	x		rfo	rfo	x				
x	x												x	x	x	x	x	x			x		RFO			fo	x
x	x												x	x	x	x	x				x		RFO			fo	x
x	x	rfo	rfo	rfo	rfo	x	x	x	x	x		rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x			x	
x	x	rfo	rfo	rfo	rfo	x	x	x	x	x		rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x			x	
x												RFO	RFO	RFO	RFO	RFO	x	x			RFO	RFO				fo	
																												RFO
x	x																										rfo	
x	x																										rfo	
x																											rfo	
x	x											RFO	RFO	RFO	RFO	RFO	x	x	x		x					x	
												rfo	rfo	rfo	rfo	rfo	x	x	x	x	x					fo	
																							RFO	x			x
																							rfo	x			x
																							rfo	x			
X																											
x		rfo				x			x			rfo	rfo	rfo	rfo	rfo			x	x						rfo	
x	x	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					x	
x	x	rfo	rfo	rfo	rfo	x	x	x	x	x	x	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x
x		rfo				x	x	x	x	x	x	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x			x	
x																											
x	x	rfo										rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x			x	
X		rfo	rfo	rfo	rfo		x	x		x	x	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x			x	x
x	x	rfo	rfo	rfo	rfo	x			x	x	x	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x	x	x	x	x	x	x
X		rfo	rfo	rfo	rfo	x	x	x	x	x	x	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x			x	
x	x	rfo		rfo	rfo		x	x	x	x	x	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x	x			
x	x	rfo		rfo	rfo	x	x	x	x	x	x	rfo	rfo	rfo	rfo	rfo	x	x	x	x	x		x				
x		rfo		rfo	rfo		x	x	x	x	x	rfo	rfo	rfo	rfo	rfo	x	x	x	x						x	
X		rfo					x	x		x	x	rfo					x	x	x	x							
x	x	rfo	rfo	rfo	rfo		x	x		x	x	rfo	rfo	rfo			x	x	x	x	x	x	x	x	x	x	x
x	x											rfo	rfo	fo			x	x	x	x	x		x			x	x
x																							x			x	x
x	x	rfo	rfo					x		x	x	rfo	rfo				x	x	x	x	x						

Appendix 2

Common and Scientific Names of Wildlife and References Used To Construct Appendix 1

Order, family, and common name	Scientific name	Reference
	AMPHIBIANS	
Caudata:		Stebbins 1951, 1966
Ambystomidae—		
long-toed salamander	*Ambystoma macrodactylum*	Anderson 1967, 1968; Farner and Kezer 1955
Anura:		Wright and Wright 1949
Pelobatidae—		
Great Basin spadefoot	*Scaphiopus intermontanus*	Bragg 1945, Mayhew 1965, Wasserman 1958
Bufonidae—		
western toad	*Bufo boreas*	Campbell 1970, Clarke 1974a, Lillywhite et al. 1973
Woodhouse toad	*Bufo woodhousei*	Bragg 1940, Clarke 1974b, Thornton 1960
Hylidae—		
Pacific treefrog	*Hyla regilla*	Brown 1975, Jameson 1956, Jameson et al. 1970
Ranidae—		
spotted frog	*Rana pretiosa*	Hollenbeck 1974, Licht 1975, Turner 1960
leopard frog	*Rana pipiens*	Hine et al. 1975, Pace 1974, Ruibal 1962
bullfrog	*Rana catesbeiana*	Darham and Bennett 1963, Sebetich 1969, Wiewandt 1969
	REPTILES	
Squamata:		Ditmars 1936, Schmidt and Davis 1941, Stebbins 1954, 1966, Wright and Wright 1957
Iguanidae—		
collared lizard	*Crotaphytus collaris*	Fitch 1956, Storm 1966, Talley[1]
leopard lizard	*Crotaphytus wislizeni*	Parker and Pianka 1976, Tanner and Krogh 1974
western fence lizard	*Sceloporus occidentalis*	Davis and Verbeek 1972, Marcellini and Mackey 1970, Rose 1976
sagebrush lizard	*Sceloporus graciosus*	Derickson 1976, Tinkle 1973, Woodbury and Woodbury 1945
side-blotched lizard	*Uta stansburiana*	Parker 1974a, Parker and Pianka 1975, Tinkle 1967
desert horned lizard	*Phrynosoma platyrhinos*	Clark and Comanor 1976, Pianka and Parker 1975, Tanner and Krogh 1973

[1]Talley, Pamela S. 1974. Report on lizard studies. Unpublished report on file at Vale District, U.S. Dep. Inter., Bur. Land Manage., Vale, Oreg.

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
short-horned lizard	*Phrynosoma douglassi*	Goldberg 1971, Heath 1965, Reeve 1952
Scincidae—		
western skink	*Eumeces skiltonianus*	Maser[2]
Teiidae—		
western whiptail	*Cnemidophorus tigris*	Apslund 1974, Burkholder and Walker 1973, Parkes 1972, Pianka 1970, Vitt and Ohmart 1977
Boidae—		Schmidt and Davis 1941
rubber boa	*Charina bottae*	Peabody et al. 1975
Colubridae—		
yellow-bellied racer	*Coluber constrictor*	Brown and Parker 1976, Fitch 1963, Herzog and Burghardt 1974
striped whipsnake	*Masticophis taeniatus*	Parker 1974b, 1976
gopher snake	*Pituophis melanoleucus*	Bogert and Roth 1966, Greenwald 1974, Stull 1940
common garter snake	*Thamnophis sirtalis*	Aleksiuk 1977, Carpenter 1952, Fitch 1965
wandering garter snake	*Thamnophis elegans*	Fox 1948, 1951
western ground snake	*Sonora semiannulata*	Talley,[3] Staedeli 1964, Stickel 1943
night snake	*Hypsiglena torquata*	Clark and Lieb 1973
Viperidae—		
western rattlesnake	*Crotalus viridis*	Klauber 1972, Parker and Brown 1974, Rahn 1942
	BIRDS	
		American Ornithologists' Union 1957, 1973a, 1973b, 1976; Bent 1926, 1961a, 1961b, 1962a, 1962b, 1962c, 1962d, 1963a, 1963b, 1963c, 1963d, 1963e, 1964a, 1964b, 1964c, 1964d, 1964e, 1964f, 1964g, 1965a, 1965b, 1968a, 1968b, 1968c; Bertrand and Scott 1973; Craighead and Craighead 1969; Gabrielson and Jewett 1970; Jackman 1974; Olendorff and Stoddart 1974; Peterson 1961; Preston and Norris 1947; Reeves 1975
Gaviiformes:		Scott et al. 1972
Gaviidae—		
common loon	*Gavia immer*	McIntyre 1975, 1978; Olson and Marshall 1952

[2]Maser, Chris. 1975-77. Unpublished data on file at Puget Sound Museum of Natural History, Univ. Puget Sound, Tacoma, Wash.

[3]Talley, Pam. [n.d.] Western ground snake, *Sonora semiannulata*. 11 p. Unpublished report on file at Vale District, U.S. Dep. Inter., Bur. Land Manage., Vale, Oreg.

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
Podicipediformes:		
Podicipedidae—		
red-necked grebe	*Podiceps grisegena*	Kebbe 1958, Kiss and Sterbetz 1973, Spahn 1978
horned grebe	*Podiceps auritus*	Faaborg 1976; Fjeldsa 1973a, 1973b; Sugden 1977
eared grebe	*Podiceps nigricollis*	Faaborg 1976; McAllister 1955, 1963; Storer et al. 1976
western grebe	*Aechmophorus occidentalis*	Feerer and Garrett 1977, Lawrence 1950, Nuechterlein 1975
pied-billed grebe	*Podilymbus podiceps*	Faaborg 1976, Glover 1953, Kirby 1976, Sealy 1978b
Pelecaniformes:		
Pelecanidae—		
American white pelican	*Pelecanus erythrorhynchos*	Johnson and Sloan 1978, Knopf 1975, Sloan 1973
Phalacrocoracidae—		
double-crested cormorant	*Phalacrocorax auritus*	Ellison and Cleary 1978, Lack 1945, Van Tets 1959
Ciconiiformes:		
Ardeidae—		
great blue heron	*Ardea herodias*	Henny and Bethers 1971, Jenni 1969, Krebs 1974, Meyerriecks 1960, Nehls 1972
green heron	*Butorides striatus*	Kushlan 1976
common egret	*Casmerodius albus*	Pratt 1970
cattle egret	*Bubulcus ibis*	Blaker 1969, Burger 1978, Curry-Lindahl 1971
black-crowned night heron	*Nycticorax nycticorax*	Allen and Mangels 1938-39, Hoffman and Prince 1975, Nickell 1966, Wolford and Boag 1971
American bittern	*Botaurus lentiginosus*	Duebbert and Lokemoen 1977
least bittern	*Ixobrychus exilis*	Weller 1961
Threskiornithidae—		
white-faced ibis	*Plegadis chihi*	Burger and Miller 1977, Ryder 1967b
Anseriformes:		Harris 1952
Anatidae—		
whistling swan	*Olor columbianus*	Scott 1977, Sherwood 1960
Canada goose	*Branta canadensis*	Jarvis and Harris 1967, Martin 1964
white-fronted goose	*Anser albifrons*	Mickelson 1975
snow goose	*Chen caerulescens*	Cooch 1958, Dzubin et al. 1975, Kerbes 1975

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
Ross' goose	*Chen rossii*	Barry 1964; Ryder 1967a, 1972
mallard	*Anas platyrhynchos*	Anderson and Henny 1972, Anderson et al. 1974, Martin and Carney 1977, Pospahala et al. 1974
gadwall	*Anas strepera*	Gates 1962, Jensen 1949, Serie and Swanson 1976
common pintail	*Anas acuta*	Fuller 1953, Krapu 1977, Rundquist 1973, Smith 1970
green-winged teal	*Anas crecca*	Bennett and Bolen 1978, Moisan 1966
blue-winged teal	*Anas discors*	Swanson and Meyer 1977, Swanson et al. 1974, Wheeler 1965
cinnamon teal	*Anas cyanoptera*	Connelly 1978, Spencer 1953
American wigeon	*Anas americana*	Gates 1958, 1962
northern shoveler	*Anas clypeata*	Girard 1939, March 1967, Poston 1974
wood duck	*Aix sponsa*	Gilmer et al. 1978, McGilvrey 1968, Wildlife Management Institute 1966
redhead	*Aythya americana*	McKnight 1974, Michot 1976, Weller 1964
ring-necked duck	*Aythya collaris*	Marshall and Duebbert 1965, Mendall 1958
canvasback	*Aythya valisineria*	Erickson 1948, Hochbaum 1944, Olson 1964, Sugden 1978
greater scaup	*Aythya marila*	Gehrman 1951
lesser scaup	*Aythya affinis*	Bartonek and Hickey 1969, Himes 1977, Rogers 1962
common goldeneye	*Bucephala clangula*	Gibbs 1961, McLaren 1962, Munro 1939
Barrow's goldeneye	*Bucephala islandica*	Griffee 1958, Munro 1939, Myres 1957
bufflehead	*Bucephala albeola*	Erskine 1960, 1961; Griffee 1961a; Munro 1942
King eider	*Somateria spectabilis*	
oldsquaw	*Clangula hyemalis*	Ellarson 1956, Rofritz 1977
ruddy duck	*Oxyura jamaicensis*	McKnight 1974, Misterek 1974, Siegfried 1977
hooded merganser	*Lophodytes cucullatus*	Griffee 1954, Kitchen 1968, Morse et al. 1969
common merganser	*Mergus merganser*	Erskine 1972, Miller and Barclay 1974
red-breasted merganser	*Mergus serrator*	Lingle and Schupbach 1977

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
Falconiformes:		Brown and Amadon 1968, Craighead and Craighead 1969
Cathartidae—		
turkey vulture	*Cathartes aura*	Coles 1938, Jackson et al. 1978, Stewart 1977
Accipitridae—		
northern goshawk	*Accipiter gentilis*	Anderson,[4] Reynolds 1978, Reynolds and Wight 1978
sharp-shinned hawk	*Accipiter striatus*	Brown 1973, Platt 1973
Cooper's hawk	*Accipiter cooperii*	Henny and Wight 1972, Meng 1952
red-tailed hawk	*Buteo jamaicensis*	Fitch et al. 1946, Gates 1972, Luttich et al. 1970
Swainson's hawk	*Buteo swainsoni*	Dunkle 1977, Fitzner 1978, Olendorff 1972
rough-legged hawk	*Buteo lagopus*	Schnell 1968, Springer 1975
ferruginous hawk	*Buteo regalis*	Wakeley 1974, Weston 1969, Wolffinden 1975
golden eagle	*Aquila chrysaetos*	Beecham and Kochert 1975, McGahan 1968, Mosher and White 1976, Murphy et al. 1969, Seibert et al. 1976, Snow 1973a
bald eagle	*Haliaeetus leucocephalus*	Mathisen et al. 1977, Murphy 1977, Platt 1976, Snow 1973b, Steenhoff 1978
northern harrier	*Circus cyaneus*	Clark and Ward 1974, Duebbert and Lokemoen 1977, Hamerstrom 1969
Pandionidae—		
osprey	*Pandion haliaetus*	Henny 1977, Henny et al. 1978, Melquist et al. 1978, Zarn 1974a
Falconidae—		
prairie falcon	*Falco mexicanus*	Denton 1976, Ogden and Hornocker 1977, Parker 1973, Snow 1974a
peregrine	*Falco peregrinus*	Hickey 1969, Porter and White 1973, Snow 1972
merlin	*Falco columbarius*	Fox 1971, Hodson 1976, Trimble 1975a
American kestrel	*Falco sparverius*	Enderson 1960, Henny et al.,[5] Smith et al. 1972
Galliformes:		
Tetraonidae—		
blue grouse	*Dendragapus obscurus*	Bendell and Elliott 1967, Donaldson and Bergerud 1974, Severson 1978, Weber et al. 1974

[4]Anderson, Ralph G. Goshawks and forest management in northeast Oregon. Unpublished data on file at U.S. Dep. Agric., Forest Service, Bear Sled Ranger District, Wallowa, Oreg. 97885.

[5]Henny, Charles J., Morlan W. Nelson, and Stephen R. Gray. 1976. Impact of 1974 DDT spraying for tussock moth control on American kestrels. 23 p. Report to USDA For. Serv., Pac. Northwest Reg., Portland, Oreg.

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
ruffed grouse	*Bonasa umbellus*	Bump et al. 1947, Moulton and Vanderschaegen 1974, Robertson 1976
sage grouse	*Centrocercus urophasianus*	Braun et al. 1977, Gray 1967, Wallestad 1975
Phasianidae—		
California quail	*Lophortyx californicus*	Anthony 1970, Storer et al. 1942, Sumner 1935
mountain quail	*Oreortyx pictus*	Gutierrez 1975, Lahnum 1944, Ormiston 1966
chukar	*Alectoris chukar*	Galbreath and Moreland 1953, Mackie and Buechner 1963, Molini 1976
gray partridge	*Perdix perdix*	McKinney 1966, Weigand 1977, Westerskov 1949
ring-necked pheasant	*Phasianus colchicus*	Allen 1956, Crouse 1941, Olsen 1977
Gruiformes:		
Gruidae—		
sandhill crane	*Grus canadensis*	Drewien and Bizeau 1974, Mullins and Bizeau 1978, Walkinshaw 1949
Rallidae—		
Virginia rail	*Rallus limicola*	Billard 1947, Glahn 1974, Horak 1964, Reeves 1975
sora	*Porzana carolina*	Billard 1947, Glahn 1974, Horak 1964, Reeves 1975
American coot	*Fulica americana*	Crawford 1977, Frederickson 1970, Jahn 1965, Jones 1940
Charadriiformes:		Stout 1967
Charadriidae—		Gerstenberg and Jurek 1972
semi-palmated plover	*Charadrius semipalmatus*	
snowy plover	*Charadrius alexandrinus*	Oregon Department of Fish and Wildlife 1977, Purdue 1974
killdeer	*Charadrius vociferus*	Bunni 1959, Lenington and Mace 1975, Mace 1978
mountain plover	*Charadrius montanus*	Graul 1975, Laun 1957
Scolopacidae—		Gerstenberg and Jurek 1972
common snipe	*Capella gallinago*	Reeves 1975, Tuck 1972, Winegardner 1976
long-billed curlew	*Numenius americanus*	Bicak 1977, Bucher 1978, McCallum et al. 1977, Sadler and Maher 1976
spotted sandpiper	*Actitis macularia*	Nelson 1939
solitary sandpiper	*Tringa solitaria*	
greater yellowlegs	*Tringa melanoleuca*	

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
lesser yellowlegs	*Tringa flavipes*	
willet	*Catoptrophorus semipalmatus*	
pectoral sandpiper	*Calidris melanotos*	Pitelka 1959
Baird's sandpiper	*Calidris bairdii*	
least sandpiper	*Calidris minutilla*	
western sandpiper	*Calidris mauri*	
long-billed dowitcher	*Limnodromus scolopaceus*	
marbled godwit	*Limosa fedoa*	
Recurvirostridae—		Gerstenberg and Jurek 1972, Wetmore 1925
American avocet	*Recurvirostra americana*	Bucher 1978, Gibson 1971
black-necked stilt	*Himantopus mexicanus*	
Phalaropodidae—		Wetmore 1925
Wilson's phalarope	*Steganopus tricolor*	Burger and Howe 1975, Hohn 1967, Johns 1969
northern phalarope	*Lobipes lobatus*	Cole 1943, Hohn 1971, Tinbergen 1935
Laridae—		
herring gull	*Larus argentatus*	Hunt 1972
California gull	*Larus californicus*	Greenhalgh 1952, Vermeer 1970
ring-billed gull	*Larus delawarensis*	Broadbooks 1961, Miller and Emlen 1975, Vermeer 1970
Franklin's gull	*Larus pipixcan*	Burger 1974, Jewett 1949
Bonaparte's gull	*Larus philadelphia*	
Forster's tern	*Sterna forsteri*	McNicholl 1971, Salt and Willard 1971, Storey 1977
Caspian tern	*Sterna caspia*	
black tern	*Chlidonias niger*	Einarsen 1941
Columbiformes:		
Columbidae—		
rock dove	*Columba livia*	Kindschy 1964; Murton et al. 1972, 1974
mourning dove	*Zenaida macroura*	Dolton 1977, Miles 1976, Ruos and Dolton 1977, U.S. Department of the Interior Fish and Wildlife Service 1962
Cuculiformes:		Trimble 1975b
Cuculidae—		
yellow-billed cuckoo	*Coccyzus americanus*	Quaintance 1944

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
Strigiformes:		Burton 1973, Craighead and Craighead 1969
Tytonidae—		
barn owl	*Tyto alba*	Henny 1969, Rudolph 1978, Smith and Marti 1976, Smith et al. 1974, Stewart 1952
Strigidae—		
common screech owl	*Otus asio*	Nowicki 1974, Smith and Wilson 1971, VanCamp and Henny 1975
flammulated owl	*Otus flammeolus*	Balda et al. 1975, Marshall 1939, Winter 1974
great horned owl	*Bubo virginianus*	Baumgartner 1939, Rusch et al. 1972, Stewart 1969
pygmy owl	*Glaucidium gnoma*	Burton 1973
burrowing owl	*Athene cunicularia*	Collins and Landry 1977, Maser et al. 1971, Zarn 1974b
long-eared owl	*Asio otus*	Glue 1977, Maser et al. 1970, Sonnenberg and Powers 1976
short-eared owl	*Asio flammeus*	Banfield 1947, Clark 1975, Marti 1974
saw-whet owl	*Aegolius acadicus*	Forbes and Warner 1974, Kebbe 1959, Woods 1972
Caprimulgiformes:		Trimble 1975b
Caprimulgidae—		
poorwill	*Phalaenoptilus nuttallii*	Horn and Marshall 1975
common nighthawk	*Chordeiles minor*	Armstrong 1965, Dexter 1961, Rust 1947, Selander 1954
Apodiformes:		Trimble 1975b
Apodidae—		
black swift	*Cypseloides niger*	
Vaux's swift	*Chaetura vauxi*	Baldwin and Hunter 1963, Baldwin and Zaczkowski 1963, Griffee 1961b, Thompson 1977
white-throated swift	*Aeronautes saxatalis*	Weber 1975
Trochilidae—		Greenwalt 1960
black-chinned hummingbird	*Archilochus alexandri*	
broad-tailed hummingbird	*Selasphorus platycercus*	Calder 1973, Calder and Booser 1973, Lyon 1973
rufous hummingbird	*Selasphorus rufus*	Gass et al. 1976, Horvath 1964
calliope hummingbird	*Stellula calliope*	Calder 1971, 1973
Anna's hummingbird	*Calypte anna*	Pitelka 1951b, Stiles 1971, Stiles and Wolf 1973

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
Coraciiformes:		Trimble 1975b
Alcedinidae—		
belted kingfisher	*Megaceryle alcyon*	Hamas 1974, Kilham 1974
Piciformes:		
Picidae—		Conner 1973, Conner et al. 1975, 1976, Jackman 1974
common flicker	*Colaptes auratus*	Anderson 1972, Conner 1973
yellow-bellied sapsucker	*Sphyrapicus varius*	Erskine and McLaren 1972, Kilham 1971a, Lawrence 1967
Williamson's sapsucker	*Sphyrapicus thyroideus*	Crockett and Hansley 1977, Michael 1936
Lewis' woodpecker	*Picoides lewis*	Bock 1970, Bock et al. 1971
hairy woodpecker	*Picoides villosus*	Kilham 1968a, Lawrence 1967, Staebler 1949
downy woodpecker	*Picoides pubescens*	Jackson 1970, Lawrence 1967, Staebler 1949
white-headed woodpecker	*Picoides albolarvatus*	Ligon 1973
Passeriformes:		Verner and Wilson 1969
Tyrannidae—		Trimble 1975b
eastern kingbird	*Tyrannus tyrannus*	Dick and Rising 1965, Hespenheide 1964, Morehouse and Brewer 1968
western kingbird	*Tyrannus verticalis*	Dick and Rising 1965, Ohlendorf 1974
ash-throated flycatcher	*Myiarchus cinerascens*	
Say's phoebe	*Sayornis saya*	Ohlendorf 1976, Whitaker 1974
willow flycatcher	*Empidonax traillii*	Aldrich 1955, King 1955, Robbins 1974
Hammond's flycatcher	*Empidonax hammondii*	Beaver and Baldwin 1975, Davis 1954, Manuwal 1970
gray flycatcher	*Empidonax wrightii*	Johnson 1963, Lavers 1975, Russell and Woodbury 1941
western flycatcher	*Empidonax difficilis*	Brodkorb 1949, Davis et al. 1963
western wood pewee	*Contopus sordidulus*	
olive-sided flycatcher	*Nuttallornis borealis*	
Alaudidae—		
horned lark	*Eremophila alpestris*	Beason and Franks 1974, Pickwell 1931, Verbeek 1967
Hirundinidae—		Trimble 1975b
violet-green swallow	*Tachycineta thalassina*	Combellack 1954
tree swallow	*Iridoprocne bicolor*	Chapman 1935, Kuerzi 1940-41
bank swallow	*Riparia riparia*	Freer 1977, Petersen 1955, Stoner 1936

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
rough-winged swallow	*Stelgidopteryx ruficollis*	Lunk 1962
barn swallow	*Hirundo rustica*	Henny 1972, Jackson and Burchfield 1975, Mason 1953
cliff swallow	*Petrochelidon pyrrhonota*	Buss 1942, Emlen 1952, Mayhew 1958
Corvidae—		Jollie 1976, Trimble 1975b, Turcek and Kelso 1968
gray jay	*Perisoreus canadensis*	Aldrich 1943, Ouellet 1970, Rutter 1969
Steller's jay	*Cyanocitta stelleri*	Brown 1963
scrub jay	*Aphelocoma coerulescens*	Pitelka 1951a
black-billed magpie	*Pica pica*	Bock and Lepthien 1975, Brown 1957, Erpino 1968, Jones 1960
northern raven	*Corvus corax*	Larsen and Dietrich 1970, Maser 1975, Montevecchi 1978
American crow	*Corvus brachyrhynchos*	Good 1952, Montevecchi 1976, Platt 1956
pinyon jay	*Gymnorhinus cyanocephalus*	Balda and Bateman 1971, Bateman and Balda 1973, Ligon and Martin 1974
Clark's nutcracker	*Nucifraga columbiana*	Giuntoli and Mewaldt 1978, Mewaldt 1956, Tomback 1977
Paridae—		Trimble 1975b
black-capped chickadee	*Parus atricapillus*	Henny 1972; Kessel 1976; Odum 1941a, 1941b; Sturman 1968
mountain chickadee	*Parus gambeli*	Dixon 1961, Kluyver 1961
bushtit	*Psaltriparus minimus*	Ervin 1977
Sittidae—		
white-breasted nuthatch	*Sitta carolinensis*	Kilham 1968b, 1971b, 1972
red-breasted nuthatch	*Sitta canadensis*	Anderson 1976, Kilham 1973, Stallcup 1968
Certhiidae—		
brown creeper	*Certhia familiaris*	Apfelbaum and Haney 1977, McClelland 1975, McClelland and Frissell 1975
Cinclidae—		
dipper	*Cinclus mexicanus*	Parsons 1975, Price and Bock, 1973, Thut 1970
Troglodytidae—		Trimble 1975b
house wren	*Troglodytes aedon*	Kendeigh 1941, Kroodsma 1973
winter wren	*Troglodytes troglodytes*	Armstrong 1956, Evenden 1950
marsh wren	*Cistothorus palustris*	Kale 1965; Verner 1963, 1975; Verner and Engelsen 1970

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
canyon wren	*Catherpes mexicanus*	Grinnell and Behle 1935
rock wren	*Salpinctes obsoletus*	Kroodsma 1975
Mimidae—		Trimble 1975b
gray catbird	*Dumetella carolinensis*	Fletcher and Smith 1978, Harcus 1973
brown thrasher	*Toxostoma rufum*	
sage thrasher	*Oreoscoptes montanus*	Reynolds and Rich 1978, Rich 1978b
Turdidae—		Trimble 1975b
American robin	*Turdus migratorius*	Farner 1949, Henny 1972, James and Shugart 1974
varied thrush	*Ixoreus naevius*	Martin 1970
hermit thrush	*Catharus guttatus*	Cochran et al. 1967, Morse 1972, Noon 1977
Swainson's thrush	*Catharus ustulatus*	Morse 1972, Noon 1977
veery	*Catharus fuscescens*	Aldrich 1939, Bertin 1977, Noon 1977
western bluebird	*Sialia mexicana*	Herlugson 1978, Pinkowski 1978
mountain bluebird	*Sialia currucoides*	Haecker 1948, Pinkowski 1978, Power 1966
Townsend's solitaire	*Myadestes townsendi*	Lederer 1977a, 1977b; Solomonson and Balda 1977
Sylviidae —		Trimble 1975b
blue-gray gnatcatcher	*Popioptila caerulea*	
ruby-crowned kinglet	*Regulus calendula*	
Motacillidae—		
water pipit	*Anthus spinoletta*	Gibb 1956, Verbeek 1970
Bombycillidae—		
Bohemian waxwing	*Bombycilla garrulus*	Bakke 1977, Knapton and Sexton 1978
cedar waxwing	*Bombycilla cedrorum*	Burleigh 1963, Gollob and Pulich 1978
Laniidae—		
northern shrike	*Lanius excubitor*	Cade 1962, 1967; Davis 1974
loggerhead shrike	*Lanius ludovicianus*	Craig 1978; Porter et al. 1975; Smith 1973a, 1973b
Sturnidae—		
European starling	*Sturnus vulgaris*	Bray et al. 1975, DeHaven and DeHaven 1973, Planck 1967
Vireonidae—		Chapin 1925, Trimble 1975b
solitary vireo	*Vireo solitarus*	Hamilton 1962; James 1973, 1976
red-eyed vireo	*Vireo olivaceus*	Lawrence 1953, Southern 1958, Williamson 1971

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
warbling vireo	*Vireo gilvus*	James 1976
Parulidae—		Griscom and Sprunt 1957, Trimble 1975b
orange-crowned warbler	*Vermivora celata*	Ficken and Ficken 1962a
Nashville warbler	*Vermivora ruficapilla*	Lawrence 1948, Roth 1977
yellow warbler	*Dendroica petechia*	Ficken and Ficken 1965, Morse 1973
yellow-rumped warbler	*Dendroica coronata*	Hubbard 1969
black-throated gray warbler	*Dendroica nigrescens*	
Townsend's warbler	*Dendroica townsendi*	
ovenbird	*Seiurus aurocapillus*	Littlefield and Mclaury 1975, Stenger 1958, Zach 1978
MacGillivray's warbler	*Oporornis tolmiei*	
common yellowthroat	*Geothlypis trichas*	Hofslund 1959, Wunderle 1978
yellow-breasted chat	*Icteria virens*	Ficken and Ficken 1962b, Stewart 1953, Thompson and Nolan 1973
Wilson's warbler	*Wilsonia pusilla*	Stewart et al. 1977
American redstart	*Setophaga ruticilla*	Ficken and Ficken 1967, McLaren 1975, Morse 1973
Ploceidae— house sparrow	*Passer domesticus*	Kendeigh 1973, Summers-Smith 1967, Summers-Smith and Pinowski 1968
Icteridae— bobolink	*Dolichonyx oryzivorus*	Martin 1974
western meadowlark	*Sturnella neglecta*	Anderson and Merrill 1967, Lanyon 1957
yellow-headed blackbird	*Xanthocephalus xanthocephalus*	Willson 1966, Willson and Orians 1963
red-winged blackbird	*Agelaius phoeniceus*	Cutright 1973, Dolbeer 1978, Krapu 1978, Robertson 1972
northern oriole	*Icterus galbula*	Pleasants 1977, Schaefer 1976
Brewer's blackbird	*Euphagus cyanocephalus*	Hansen and Carter 1963, Horn 1968, Stepney 1975
brown-headed cowbird	*Molothrus ater*	Friedmann 1963, Hill 1976, Payne 1976
Thraupidae— western tanager	*Piranga ludoviciana*	Trimble 1975b
Fringillidae—		Trimble 1975b
rose-breasted grosbeak	*Pheucticus ludovicianus*	Kroodsma 1974, Lemon and Chatfield 1973

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
black-headed grosbeak	*Pheucticus melanocephalus*	Kroodsma 1974
indigo bunting	*Passerina cyanea*	Emlen et al. 1975, Wells 1958, Whitmore 1975
lazuli bunting	*Passerina amoena*	Emlen et al. 1975, Thompson 1976, Whitmore 1975
evening grosbeak	*Hesperiphona vespertina*	Balph and Balph 1976, Blais and Parks 1964, Dexter 1975
purple finch	*Carpodacus purpureus*	Pulliam and Enders 1971
Cassin's finch	*Carpodacus cassinii*	Balph 1978, Herman 1971, Samson 1976
house finch	*Carpodacus mexicanus*	Thompson 1960
common redpoll	*Carduelis flammea*	Evans 1969; Kennard 1976; Pohl and West 1976, 1978
pine siskin	*Carduelis pinus*	Eriksson 1970, Harris 1975
American goldfinch	*Carduelis tristis*	Holcomb 1969, Miller 1978, Nickell 1951
lesser goldfinch	*Carduelis psaltria*	
green-tailed towhee	*Pipilo chlorura*	
rufous-sided towhee	*Pipilo erythrophthalmus*	Baumann 1959, Davis 1960, Greenlaw 1978
savannah sparrow	*Passerculus sandwichensis*	Bradley 1973, Dixon 1978, Welsh 1975, Wiens 1973
grasshopper sparrow	*Ammodramus savannarum*	Pulliam and Mills 1977, Smith 1963, Wiens 1973
vesper sparrow	*Pooecetes gramineus*	Best 1972, Pulliam and Mills 1977, Simpson 1978
lark sparrow	*Chondestes grammacus*	Renwald 1977
sage sparrow	*Amphispiza belli*	Braun et al. 1976, Moldenhauer 1970, Moldenhauer and Wiens 1970, Rich 1978a
northern junco	*Junco hyemalis*	Balph 1977, Gottfried and Franks 1975, Sabine 1959
American tree sparrow	*Spizella arborea*	Anderson 1973, Heydweiller 1935, Stenger 1965, Weeden 1958
chipping sparrow	*Spizella passerina*	Hebrard 1978, Klopfer 1965, Pulliam and Mills 1977
Brewer's sparrow	*Spizella breweri*	Best 1972, Braun et al. 1976, Rich 1978a
white-crowned sparrow	*Zonotrichia leucophrys*	Cortopassi and Mewaldt 1965, Lewis 1975, Morton et al. 1972, Rees 1973
golden-crowned sparrow	*Zonotrichia atricapilla*	Balph 1976

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
fox sparrow	*Passerella iliaca*	Banks 1970
Lincoln's sparrow	*Melospiza lincolnii*	Miller 1939, Miller and McCabe 1935
song sparrow	*Melospiza melodia*	Knapton and Krebs 1974, Nice 1943, Tompa 1962
Lapland longspur	*Calcarius lapponicus*	
snow bunting	*Plectrophenax nivalis*	Nethersole-Thompson 1966, Tinbergen 1939
	MAMMALS	
		Bailey 1936, Burt and Grossenheider 1964, Hall and Kelson 1959, Hansen 1956, Harvey 1976, McDaniel and Gardner 1977, McReynolds 1976, Mohr 1976, Shay 1973
Insectivora:		Terry 1978, Whitaker and Maser 1976
Soricidae—		
Malheur shrew	*Sorex preblei*	Armstrong 1957, Hoffman and Fisher 1978, Verts 1975
wandering shrew	*Sorex vagrans*	Clothier 1955, Hooven et al. 1975, Ingles 1961
Merriam shrew	*Sorex merriami*	Gashwiler 1976, Johnson and Clanton 1954, Lindsay and Perry 1977
Chiroptera:		Barbour and Davis 1969, Cross 1977, Saul et al. 1977
Vespertilionidae—		
little brown myotis	*Myotis lucifugus*	Buchler 1976, Fenton 1970, O'Farrell and Studier 1973
Yuma myotis	*Myotis yumanensis*	Dalquest 1947a
long-eared myotis	*Myotis evotis*	Dalquest 1948
fringed myotis	*Myotis thysanodes*	O'Farrell and Studier 1973, 1975
long-legged myotis	*Myotis volans*	Whitaker et al. 1977
California myotis	*Myotis californicus*	Krutzsch 1954, Whitaker et al. 1977
small-footed myotis	*Myotis leibi*	Fenton 1972, Tuttle and Heaney 1974
silver-haired bat	*Lasionycteris noctivagans*	Whitaker et al. 1977
western pipistrelle	*Pipistrellus hesperus*	Cross 1965, Hoff and Riedesel 1969
big brown bat	*Eptesicus fuscus*	Christian 1956, Davis et al. 1968, Kunz et al. 1977, Mills et al. 1975
hoary bat	*Lasiurus cinereus*	Constantine 1966, Findley and Jones 1964, Jones 1965, Sealy 1978a

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
spotted bat	*Euderma maculata*	Easterla 1971, Snow 1974b, U.S. Department of the Interior Bureau of Sport Fisheries and Wildlife 1973
western big-eared bat	*Plecotus townsendi*	Dalquest 1947b, Humphrey and Kunz 1976, Pearson et al. 1952
pallid bat	*Antrozous pallidus*	Beck and Rudd 1960, Davis 1969, Orr 1954
Lagomorpha:		
Leporidae—		
pygmy rabbit	*Sylvilagus idahoensis*	Orr 1940, Severaid 1950
mountain cottontail	*Sylvilagus nuttalli*	Chapman 1975, McKay and Verts 1978, Orr 1940
white-tailed jackrabbit	*Lepus townsendi*	Bear and Hansen 1966; James and Seabloom 1969a, 1969b
black-tailed jackrabbit	*Lepus californicus*	Blackburn 1968, Gross et all. 1974, Haskell and Reynolds 1947
Rodentia:		
Sciuridae—		
least chipmunk	*Eutamias minimus*	Meredith 1976, Sheppard 1965, Skryja 1974
yellow-pine chipmunk	*Eutamias amoenus*	Broadbooks 1958, 1970a, 1970b
yellow-bellied marmot	*Marmota flaviventris*	Armitage 1975, Armitage and Downhower 1974, Garrott and Jenni 1978
antelope ground squirrel	*Ammospermophilus leucurus*	Bradley 1967, 1968
Townsend ground squirrel	*Spermophilus townsendi*	Dalquest 1948, Johnson 1977, Shaw 1921
Richardson ground squirrel	*Spermophilus richardsoni*	Michener 1977, Michener and Michener 1977, Zegers 1976
Belding ground squirrel	*Spermophilus beldingi*	Morton and Gallup 1975, Morton and Sherman 1978, Turner 1972
mantled ground squirrel	*Spermophilus lateralis*	Gordon 1943, Tevis 1952, Yousef and Bradley 1971
Geomyidae—		
Townsend pocket gopher	*Thomomys townsendi*	Hall 1946, Horn 1923
northern pocket gopher	*Thomomys talpoides*	Anderson 1976, Hansen and Beck 1968, Julander et al. 1969
Heteromyidae—		
little pocket mouse	*Perognathus longimembris*	
Great Basin pocket mouse	*Perognathus parvus*	Hedlund et al. 1975, Kritzman 1974, O'Farrell et al. 1975, Scheffer 1938
dark kangaroo mouse	*Microdipodops megacephalus*	Ghiselin 1970, O'Farrell and Blaustein 1974

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
Ord kangaroo rat	*Dipodomys ordi*	Blaustein and Risser 1976, Lemen and Rosenzweig 1978, Whitford 1976
chisel-toothed kangaroo rat	*Dipodomys microps*	Beatley 1976, Jorgensen 1963, Kenagy 1973
Castoridae— beaver	*Castor canadensis*	Ffolliott 1976, Leege 1968, Rutherford 1964
Cricetidae— western harvest mouse	*Reithrodontomys megalotis*	Birkenholz 1967, Fisler 1971, Whitaker and Mumford 1972
canyon mouse	*Peromyscus crinitus*	Egoscue 1964, Lechleitner 1969
deer mouse	*Peromyscus maniculatus*	Blair 1943, King 1968, Kritzman 1974, Lawlor 1976, Wirtz and Pearson 1960
northern grasshopper mouse	*Onychomys leucogaster*	Egoscue 1960, McCarty 1978, Ruffer 1965
desert woodrat	*Neotoma lepida*	Bleich and Schwartz 1975, Stones and Hayward 1968
bushy-tailed woodrat	*Neotoma cinerea*	Findley 1958, Johnson and Hansen 1979
Microtidae— montane vole	*Microtus montanus*	Murie 1971, Murray 1965, Randall 1978
long-tailed vole	*Microtus longicaudus*	Beck and Anthony 1971, Randall 1978
sage vole	*Lagurus curtatus*	Clanton et al. 1971, Johnson et al. 1948, Maser et al. 1974, Maser and Strickler 1978
muskrat	*Ondatra zibethicus*	Kiviat 1978, Neal 1968b, Sather 1958, Willner et al. 1975
Zapodidae— western jumping mouse	*Zapus princeps*	Brown 1967, Cranford 1978, Jones et al. 1978
Erethizontidae— porcupine	*Erethizon dorsatum*	Hooven 1971, Smith 1977
Canidae— coyote	*Canis latrans*	Gier 1968, Knowlton 1972, Mathwig 1973
red fox	*Vulpes vulpes*	Sheldon 1949, Stanley 1963, Storm et al. 1976
kit fox	*Vulpes macrotis*	Egoscue 1975, Laughrin 1970, Snow 1973c
Procyonidae— raccoon	*Procyon lotor*	Fritzell 1978, Schneider et al. 1971, Urban 1970
Mustelidae—		Hamilton 1933, Heidt et al. 1976
long-tailed weasel	*Mustela frenata*	Hall 1951

Appendix 2 (continued)

Order, family, and common name	Scientific name	Reference
mink	*Mustela vison*	Errington 1943, Northcott et al. 1974, Shump et al. 1976a
badger	*Taxidea taxus*	Lindzey 1978, Sargeant and Warner 1972
spotted skunk	*Spilogale putorius*	Baker and Baker 1975, Crabb 1948, Patton 1974
striped skunk	*Mephitis mephitis*	Bailey 1971, Shump et al. 1975, Verts 1967
river otter	*Lutra canadensis*	Shump et al. 1976b, Tabor and Wight 1977, Toweill 1974
Felidae—		
cougar	*Felis concolor*	Hornocker 1970, Seidensticker et al. 1973, Sitton 1977
bobcat	*Lynx rufus*	Crowe 1975, Gashwiler et al. 1961, Sweeney 1977
Artiodactyla:		
Cervidae—		
mule deer	*Odocoileus hemionus*	Dealy 1970
Antilocapridae—		
pronghorn	*Antilocapra americana*	Autenrieth and Fichter 1975, Kitchen 1974, Sundstrom et al. 1973, Yoakum 1967
Bovidae—		
bighorn sheep	*Ovis canadensis*	Berger 1978, McGlinchy et al. 1971, Spalding and Mitchell 1970

WILDLIFE HABITATS IN MANAGED RANGELANDS — THE GREAT BASIN OF SOUTHEASTERN OREGON

Technical Editors

JACK WARD THOMAS, U.S. Department of Agriculture, Forest Service

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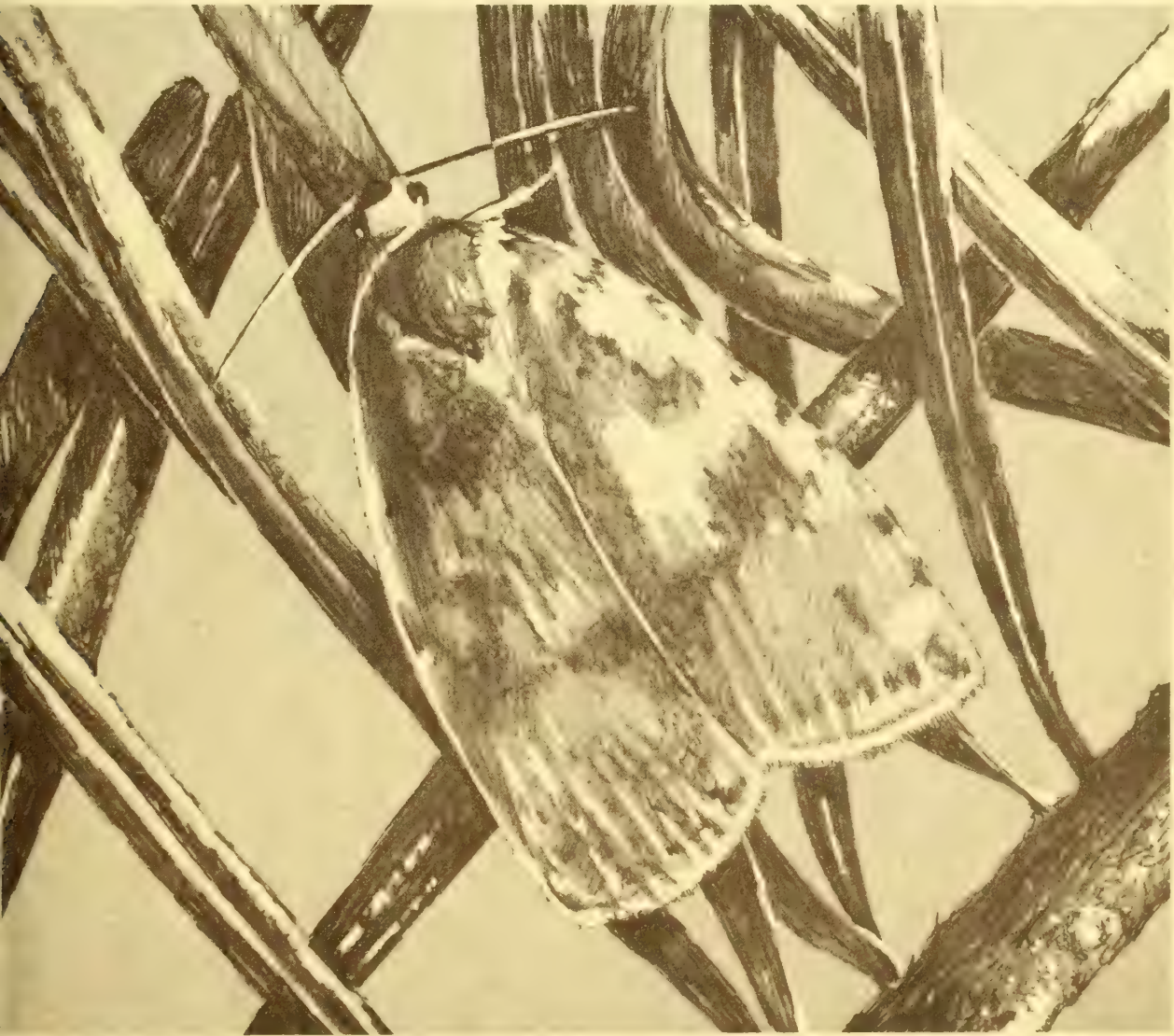
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Nomenclature of Nearctic Conifer-Feeding *Choristoneura* (Lepidoptera: Tortricidae): HISTORICAL REVIEW AND PRESENT STATUS

Jerry A. Powell



ABSTRACT

There have been 18 species-group names proposed for Nearctic conifer-feeding moths in the genus Choristoneura. Of these, houstonana (Grote) and its synonym, retana (Walsingham), apply to Cupressaceae-feeding populations now assigned to Cudonigera Obraztsov & Powell. The remaining species are Pinaceae-feeders, mostly members of two series: (1) the Fumiferana complex, associated with spruces and firs (subfamily Abietoideae) and considered to consist of 5 allopatric species (with three synonyms); and (2) the Lambertiana complex, feeding on pines (subfamily Pinoideae) and consisting of two allopatric species, the western C. lambertiana (Busck) with three subspecies and the eastern C. pinus Freeman with two subspecies. A third group, the Carnana complex, is believed to be associated with Douglas-fir (Pseudotsuga). Its populations occur in California, with two named races, sympatric with elements of both the Abietoideae- and Pinoideae-feeding complexes. One named entity, spaldingiana Obraztsov, in Utah, is of unknown affinities.

Keywords: Nomenclature (insect), Choristoneura.

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Possibly no species of Lepidoptera has been more intensively studied during the past quarter century than the spruce budworm in North America, yet the nomenclature of the Choristoneura fumiferana group has continued to be confusing. Although some problems are traceable to premature or careless taxonomic work, the principal source of turmoil lies in the complexity of variation among populations. An array of interrelationships exists; sympatric populations exhibit varying degrees of reproductive isolation, and allopatric populations show geographical variations in size and color of adults, larvae, and pupae and in preferences for host plants. There are both polymorphic and continuously variable features, and characters conventionally used by taxonomists in defining species in moths are not sufficiently differentiated in this group to provide reliable morphological indicators of genetic and behavioral compatibility among populations.

An increase in research on the Nearctic conifer-feeding Choristoneura as a result of the Canada/U.S. Spruce Budworms Program, launched in 1977, has broadened interest in and the need for better communication about these insects. Despite considerable funding and intricate organizational planning, disagreement exists concerning the number, level of taxonomic distinctness, and geographical distributions of species and races, as well as the names applied to them. Thus, an updated summary of nomenclature in this species group and agreement among researchers about correct application of names seem essential.

Moreover, a revised checklist of North American Lepidoptera, which has been several years in preparation by a team of specialists, is nearly completed--the first updated list in 4W years (Hodges et al., in press). Acceptance of the nomenclature in this list by the U.S. Department of Agriculture and the Entomological Society of America (and therefore the E.S.A. common names list--Sutherland et al. 1978) is anticipated. This should provide a considerably stronger base for stabilization of names of all North American Lepidoptera. I have contributed the text for the Tortricidae, aided by reviews and contributions from several contemporary specialists, including R. W. Brown, R. W. Hodges, and W. E. Miller. Table 1 lists valid and synonymous names applied to conifer-feeding Choristoneura and Cudonigera as they will be treated in Hodges' (in press) checklist.

In general, the checklist is not envisioned as a vehicle for revising taxonomic work, but there will be many nomenclatural changes. Names formerly applied in many taxa have become obsolete as a result of taxonomic study of Nearctic or other faunas, particularly the Palearctic. Authors have been expected to incorporate nomenclatural changes where firsthand taxonomic expertise enables generic reassignments and synonymies. Therefore, many new combinations and new synonymies will be published in the checklist without explanations. In most instances, explanations would be of interest only to specialists, but in a few cases the importance of the insects in agricultural entomology or other applied fields is such that

published interpretation is warranted. Because the Canada/U.S. Spruce Budworms Program is in its early phases, the spruce budworm complex is such a case.

Table 1--Checklist of valid and synonymous names used for North American conifer-feeding Choristoneura and Cudonigera (synonyms underlined)1/

Choristoneura Lederer, 1859
  fumiferana (Clemens, 1865)
    nigridia (Robinson, 1869)
  retiniana (Walsingham, 1879)
    lindseyana Obraztsov, 1962
    viridis Freeman, 1967
  occidentalis Freeman, 1967
  biennis Freeman, 1967
  orae Freeman, 1967
  carnana (Barnes & Busck, 1920)
    c. californica Powell, 1964
  lambertiana (Busck, 1915)
    l. ponderosana Obraztsov, 1962
    l. subretiniana Obraztsov, 1962
  pinus Freeman, 1953
    p. maritima Freeman, 1967
  spaldingiana Obraztsov, 1962
Cudonigera Obraztsov & Powell, 1977
  houstonana (Grote, 1873)
    retana (Walsingham, 1879)

1/After Powell in Hodges et al. (in press).

fumiferana Clemens, 1865, Proc. Entomol. Soc. Phila. 5:129 (Tortrix)

The earliest name applied to any North American conifer-feeding Choristoneura is fumiferana, described from "Virginia." A lectotype was designated by Darlington (1947), who indicted there are no data associated with the specimen, as is true of Clemens' material generally (see Miller (1973) for a review of the history and status of Clemens' types and associated catalog numbers). Thus, the accuracy or any restriction of the type locality cannot be determined. Treated in Tortrix or Harmologa, a New Zealand genus, in early literature, the species later was placed in Archips (= Cacoecia) until Freeman (1947) assigned fumiferana to the Palearctic genus Choristoneura.

nigridia Robinson, 1869, Trans. Am. Entomol. Soc. 2:268 (Tortrix)

Described from "Ohio, Pa., and Mass.," this is the only synonymous name proposed for the widespread spruce budworm of eastern Nearctic boreal forests. Darlington (1947) mentioned a cotype at the Academy of Natural Sciences, Philadelphia; but apparently no formal designation of a lectotype and restriction of the type locality has been made. Representative specimens of type material of nigridia and fumiferana were examined by Fernald in the 1870's (Darlington 1947, p. 86), who concluded the two are synonyms (Fernald 1881, p. 63).

houstonana Grote, 1873, Bull. Buffalo Soc. Nat. Sci.:15 (Tortrix)

The next oldest name used for a conifer-feeding moth formerly considered a member of Choristoneura is houstonana Grote, which was based on a specimen from "Texas." The type specimen is believed to be no longer extant. A synonym, retana Walsingham, is available, but the species is distinctive, and Grote's description seems unequivocal so that neither suppression of it as a nomen dubium nor designation of a neotype seems necessary. This species was included in Choristoneura (Freeman 1958, Powell 1964); but recently Cudonigera Obraztsov and Powell was proposed for houstonana, primarily on the basis of morphological features of the adult which differ markedly from all other Choristoneura (Powell and Obraztsov 1977). Cudonigera houstonana feeds exclusively on Juniperus (Cupressaceae) (Powell 1964, Heinrichs and Thompson 1968); all other Nearctic conifer-feeding Choristoneura are restricted to Pinaceae (Stehr 1967).

retana Walsingham, 1879, illus. Lepid. Het. Br. Mus. 4:13 (Lozotaenia)

This name was recognized by Grote (1881, p. 9) as synonymous with houstonana, a conclusion accepted by subsequent workers. The type locality, cited as "Texas," is Bosque County, Texas, according to data on the lectotype (Powell and Obraztsov 1977).

retiniana Walsingham, 1879, illus. Lepid. Het. Br. Mus. 4:12 (Lozotaenia)

The earliest name applied to any western budworm is retiniana Walsingham, described from one specimen collected at Mount Shasta, California, in 1871. Failure to recognize its status by most subsequent taxonomists precluded use of this name in literature on budworms. Generally, it was listed in the genus Archips by earlier workers, but Freeman (1958) transferred retiniana to Choristoneura, suggesting that it might be related to the pine-feeding species. Freeman illustrated a specimen from Mono County, California, as representing retiniana.

Obraztsov (1962) recognized that Freeman's asssumption was based on a misidentification of moths now called subretiniana Obraztsov, a pine-feeder. Obraztsov illustrated structural features of the holotype of retiniana and presented photographs of specimens from Oregon and New Mexico which he supposed to be conspecific. Powell (1964) applied the concept of fumiferana Clemens broadly, to include all fir- and spruce-feeding populations, and recognized retiniana as a synonym because pale specimens of Abies-feeding populations in Modoc County (about 150 km--90 miles--east of Mount Shasta) resemble Walsingham's description and illustration of retiniana.

lambertiana Busck, 1915, Proc. Entomol. Soc. Wash. 17:86 (Tortrix)

The earliest name proposed for any pine-feeding population in Nearctic Choristoneura is lambertiana Busck, described from Ashland, in southern Oregon (Jackson County). The locality was originally given as "Oakland," Oregon, but the type series is from Ashland according to the labels and Hopkins' data. Some of the labels are printed by machine, and some are handwritten; the latter were evidently misread by Busck. The species was assigned to Choristoneura by Freeman (1958), who listed the species also from California and New Mexico without specific data. The concept of lambertiana was broadened by Obraztsov (1962) to include populations in Idaho, Montana, Wyoming, and New Mexico.

carnana Barnes and Busck, 1920, Contr. Nat. Hist. Lepid. N.A. 4(3):214 (Tortrix)

This distinctive, rust- and white-colored moth was described on the basis of specimens labeled "Camp Baldy, San Bernardino Mountains, California." The type locality presumably is at or near the place now known as Mount Baldy Post Office (designated as Camp Baldy on roadmaps as recently as 1947), which is situated at about 1 300-m (4,250-foot) elevation near the Los Angeles-San Bernardino County line in the San Gabriel Mountains. There have been no verified records from the San Bernardino Mountains. The species was recognized as a Choristoneura related to fumiferana by Freeman (1958), and subsequently carnana was treated as a subspecies of lambertiana (Powell 1964).

pinus Freeman, 1953, Can. Entomol. 85:122 (Choristoneura)

This name was provided by Freeman for pine-feeding populations of eastern Canada, following extensive studies by several researchers on differences in biology, phenology, immature stages, parasites, and isolating mechanisms between this and the sympatric Choristoneura fumiferana. The type locality is Beausejour, Manitoba.

spaldingiana Obraztsov, 1962, Am. Mus. Novit. 2101:6 (Choristoneura)

This species was described from Provo, Utah, on the basis of a single male specimen.

subretiniana Obraztsov, 1962, Am. Mus. Novit. 2101:9 (Choristoneura)

Using specimens from "Monachee," Tulare County, California, 8,000 feet (2 450 m), Obraztsov described subretiniana. Presumably this is the site now called Monache Meadows, situated near the headwaters of the south fork of the Kern River, west of Olancha Pass in the southern Sierra Nevada. This race was treated as a subspecies of lambertiana by Powell (1964) on the basis of phenotypic similarity of adults in populations of the central and northern Sierra Nevada and the pine-feeding population of Warner Mountains, Modoc County, and because of the allopatric occurrence of these populations in relation to lambertiana s. str. and californica Powell west of the Sierran crest.

ponderosana Obraztsov, 1962, Am. Mus. Novit. 2101:14 (Choristoneura)

In broadening the concept of lambertiana, Obraztsov recognized similarity of moths in Colorado to those of the northern Rockies which he treated as lambertiana, and he designated a series reared from ponderosa pine at Sugar Loaf, Boulder County, as ponderosana.

lindseyana Obraztsov, 1962, Am. Mus. Novit. 2101:16 (Choristoneura)

A collection of Choristoneura was made by A. W. Lindsey in the Davis Creek area of the Warner Mountains, Modoc County, California, in 1922. Included were nearly 100 specimens representing each of two populations now known to be fir-feeding and pine-feeding species and referred to as retiniana and subretiniana, respectively. A portion of the polymorphic Abies-feeding population there consists of individuals with pale tan forewings without dark markings, and this form was selected by Obraztsov to name. He supposed this to be a subspecies of lambertiana, despite the fact that specimens phenotypically similar to subretiniana had been collected by Lindsey in the Warner Mountains, and others had been reared by USDA Forest Service researchers from lodgepole pine in 1952-53 (Powell 1964, p. 183). In treating fumiferana broadly, I relegated lindseyana to synonymy, recognizing the tan form as a polymorph phase in samples reared from Abies (Powell 1964, p. 175).

I pointed out that Obraztsov's lindseyana types had been extracted from a series of Choristoneura "fumiferana" (= retiniana) and these matched specimens reared from Abies in the Warner Mountains during 1950-57 (Powell 1964, p. 176).

californica Powell, 1964, Univ. Calif. Publ. Entomol. 32:179 (Choristoneura)

This name was applied to populations in the North Coast Range (type locality: Anderson Springs, Lake County), southern Cascade Range, and west slope of the Sierra Nevada. Although none had been reared, larvae of these populations were assumed to be pine-feeding, and californica was associated with lambertiana as a subspecies on the basis of the allopatry with lambertiana in the strict sense to the north, subretiniana to the east, and carnana in southern California.

biennis Freeman, 1967, Can. Entomol. 99:451 (Choristoneura)

This species was distinguished primarily on the basis of the larger average size and darker coloration of adults and the fact that 2 years are required to complete the life cycle. The type locality is 8 miles (13 km) south of Cherryville (in the Monashee Mountains near Vernon) in southern British Columbia, where specimens were reared from spruce (Picea sp.) and fir (Abies lasiocarpa).

occidentalis Freeman, 1967, Can. Entomol. 99:451 (Choristoneura)

Considered to be the most widespread, dominant conifer-feeding Choristoneura in the western Nearctic, occidentalis was described from Klickitat County, Washington, reared from Pseudotsuga. Populations believed to be conspecific were recorded from New Mexico through the northern Rocky Mountain States to British Columbia and in northern California (Freeman 1967).

orae Freeman, 1967, Can. Entomol. 99:452 (Choristoneura)

This name was applied to a population at Kitimat in north coastal British Columbia. Choristoneura orae consists of small individuals which are phenotypically similar to fumiferana. The type series was reared from Abies and Picea. Differences in polymorph phases (Stehr 1964) and characteristic physiological data (Harvey 1967) appear to be the primary distinguishing features of the population.

viridis Freeman, 1967, Can. Entomol. 99:452 (Choristoneura)

On the basis of collections from Bidwell Creek, Modoc County, California, Freeman renamed the fir-feeding population of the Warner Mountains viridis, disregarding the nomenclatural priority of lindseyana for that population. Despite biological information documenting the status of lindseyana as the pale form of the fir-feeding Choristoneura and the occurrence of a sympatric pine-feeding species (Powell 1964), Freeman (1967, p. 453) listed lindseyana among several forms thought to be pine-feeders.

maritima Freeman, 1967, Can. Entomol. 99:455 (Choristoneura)

This name was proposed as a subspecies of Choristoneura pinus, to include populations from Massachusetts south to Kentucky. The type locality is Blain (Perry County) in the Allegheny Mountains of south-central Pennsylvania. Known hosts include pines of the subsections Australes and Contortae.

CURRENT STATUS OF NAMED FORMS

There are two series of populations among North American Pinaceae-feeding Choristoneura, one feeding primarily on spruces and firs of the genera Picea, Abies, amd Pseudotsuga (subfamily Abietoideae; Ferré 1952), and the other almost exclusively on Pinus (subfamily Pinoideae). For convenience, these are referred to here as the Fumiferana complex and Lambertiana complex, respectively. In each there are parallel patterns of geographical distribution, with resultant widespread sympatric pairs, one Abietoideae-feeding and one Pinoideae-feeding, in eastern and western portions of the Nearctic.

There do not seem to be documented instances of sympatric species within either the Fumiferana complex or Lambertiana complex. There is a third group of populations, however, here called the Carnana complex, for which insufficient data are available to precisely define relationships. Formerly, these were thought to be members of the Lambertiana complex, based on allopatric distributions in relation to known pine-feeding populations (Powell 1964). Recent evidence, however, indicates that the Carnana complex consists of populations feeding on Pseudotsuga, which are parapatric (Mount Shasta) or sympatric (west slope of Sierra Nevada, San Gabriel Mountains) with Abies-feeding populations of the Fumiferana complex.

Instances of larvae feeding on other than the normal Abietoideae or Pinoideae host are occasionally observed but usually only in mixed stands of conifer genera. For example, in 1974 we reared a large number of Choristoneura retiniana from late instar samples collected on Abies concolor in the Warner Mountains, California.1/ These included all larvae thought to differ from the typical green budworm in preliminary sorting, as well as random subsamples of green budworm from each collection. Of 5,368 moths reared, about 3,200 (60 percent) were C. retiniana and only about 5 (<1 percent) C. lambertiana subretiniana, which sometimes causes visible defoliation of lodgepole pine at the same localities (Pierce and Hall 1974). Stehr (1967), who attributes most such records to dispersal of young larvae in autumn or spring, states that there are no known records of oviposition on the reciprocal host leding to successful establishment of larvae. Probably some published records or data on labels of the "wrong" host are the result of misidentification of larvae or reared adults. In general, the ecological subdivision appears to be remarkably distinct.

In the Fumiferana and Lambertiana complexes, the parallel situation exists wherein each is represented in the eastern half of the continent by a widespread species that is relatively constant in biological and phenotypic characteristics, but in the western portion is more complicated. Entomologists agree that Choristoneura fumiferana is a monotypic form occurring from the McKenzie River near

[1]Powell, J. A., and V. Donahue. 1974. Monitoring the effects of Dylox on microlepidopterous larvae. USDA For. Serv., Coop. Agreement Final Rep., 17 p.

66° N, southeastward in a broad arc through southern Canada and adjacent parts of the United States, to the Maritime Provinces and Newfoundland. Choristoneura pinus is sympatric along the southern part of this range in the Great Lakes region, extending farther south than does fumiferana, in the northern Plains States, and in the Allegheny-Appalachian region, where populations are referred to as the subspecies C. pinus maritima.

West of the continental divide, populations of the Fumiferana and Lambertiana complexes are also sympatric in many areas, but there is considerably greater varability. Among western components of both the Abietoideae- and Pinoideae-feeding groups, a great deal of polytypic (interpopulational) variation exists, not only in adult and larval morphologies, but in degree of genetic polymorphism, physiological traits, and preferences for host plants. Part of the complexity can be attributed to a relatively fragmentary status of sampling compared with eastern areas. In general, however, the situation reflects real biological phenomena: the intermingling of forest tree species, small-scale patterning of pure stands, and geographical complexity of western forest regions (Eyre 1954, p. 9; Stehr 1967). The isolation or semi-isolation of populations by the islandlike distribution of mountain ranges and host tree types presumably has led to divergence and changes in mechanisms that isolate species. Probably the biological instability corresponds generally to the more recent, postglacial colonizing of these areas and the consequent reestablishment of contact between floras and faunas which were isolated during glacial advances.

Western Components of the Fumiferana Complex

Present taxonomic concepts consider this array to comprise four mainly allopatric species, the names of which have been applied through historical chance. The oldest name was given to the only representative available a century ago (Walsingham 1879); more recent names were proposed for samples of sporadically collected adults (Obraztsov 1962) or were applied to the populations which were best known through laboratory studies a decade ago (Freeman 1967).

Choristoneura retiniana (Wlsm.).--Clarification of the status of retiniana is pivotal to nomenclatural assignments. Surveys were conducted in northern California and southern Oregon in 1966-70, toward this goal.2/ Only sporadic rearing records were obtained, but sufficient population samples of moths taken at lights were accumulated to assess variation. I compared representative specimens with the holotype of retiniana at the British Museum in 1971 and established its identify with samples from McBride Springs on Mount Shasta and Donner Summit (Placer County), California (reared from Abies concolor). Obraztsov's (1962) description of the

[2]Powell, J. A. 1970. Taxonomic and biological investigations on California microlepidoptera. Univ. Calif. Agric. Exp. Stn. proj. 2063. Prog. Rep. 1970, 3 p.

retiniana type specimen as "badly denuded and damaged" is in error. The specimen is in good condition.

T. D. Eichlin of the California State Department of Food and Agriculture and I carried out further surveys in the Modoc-Siskiyou area in 1974, partly in collaboration with the USDA Forest Service, which provided samples of larvae from nine sites in Modoc County from a pilot control project of Dylox on the Modoc budworm (see footnote 1). Larval collections from Abies on Mount Shasta produced moths confirming similarities in phenotype, polymorphic variation, and the weak sclerotization of larval and pupal integument (source of the common name "green budworm") among populations there and in Modoc County. Therefore, I believe the name retiniana applies to Abies-feeding populations in the southern Cascade Range, at Mount Shasta, and in the Warner Mountains. If, in the future, the Warner Mountains population is deemed sufficiently distinguishable to warrant nomenclatural recognition, the name lindseyana Obraztsov, 1962, has priority over viridis Freeman, 1967.

Southward, in the Sierra Nevada, Tehachapi Range, and mountains of southern California, there are populations of Choristoneura that exhibit similar genetic polymorphism, having a morph with pale tan, unmarked forewings. Though the adult phenotype is much less variable than that of retiniana in Modoc County, these populations appear to be a counterpart of retiniana. Their distribution is entirely in association with Abies, and larvae reared in 1979 from Abies in El Dorado County were of the green, unmarked form. In the San Gabriel Mountains and at lower elevations (below 1 700 m--5,500 feet) in the Sierra Nevada, these retiniana-like Choristoneura are sympatric with the monomorphic, Pseudosuga-feeding C. carnana, and at higher elevations, near the Sierran crest (e.g., Lake Tahoe), with Pinus-feeding C. lambertiana subretiniana.

Northward, C. retiniana is replaced by occidentalis, either abruptly, in northern Oregon as indicated by Freeman (1967) and Stehr (1967), or gradually in a series of blend zone populations. V. M. Carolin (personal communication) states that a Choristoneura with green larvae identical to retiniana of Modoc County, California, occurs in the King Mountain area near Burns, in east-central Oregon, whereas a fir-feeding form in south-central Oregon west of Lakeview is heterogeneous, showing a gradation between retiniana and occidentalis morphs in both larvae and adults. Currently under investigation by W. J. A. Volney and W. E. Waters, University of California, Berkeley, populations in this region are critical to a more thorough understanding of the systematic and biological relationships of C. retiniana, C. carnana californica, and C. occidentalis.

Choristoneura occidentalis (Freeman).--As presently conceived, this name applied to all Abietoideae-feeding populations from northern Oregon, Washington, southern British Columbia, and the Rocky Mountain States south to New Mexico and eastern Arizona (fig. 1). Freeman (1967) also listed California in the range of occidentalis; and Stehr (1967), in his figure 1, showed a symbol for occidentalis in the vicinity of Lake Tahoe, both without indication as to

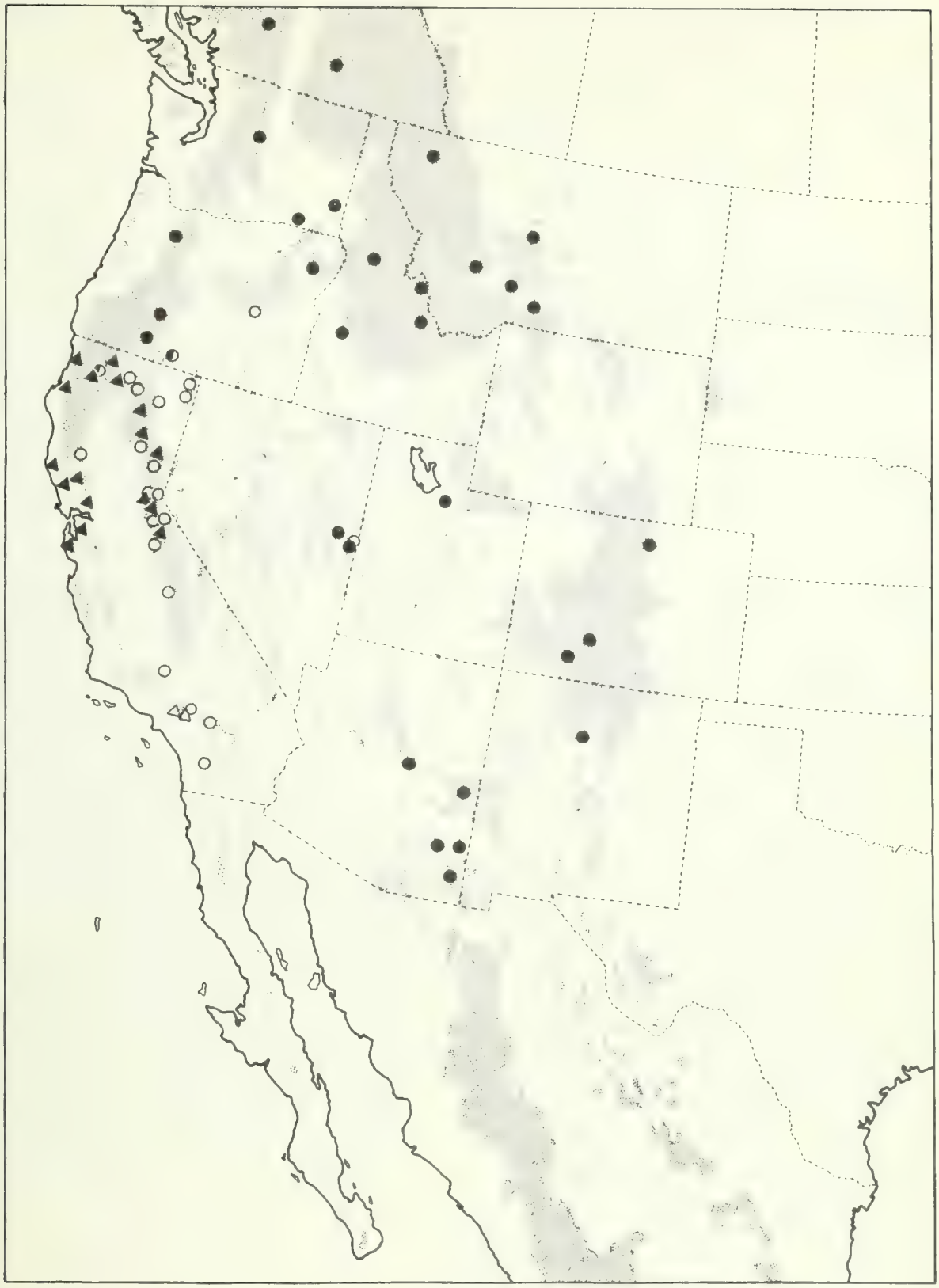


Figure 1.--Distribution of Western United States members of the Abietoideae-feeding Fumiferana and Carnana complexes: Choristoneura occidentalis Freeman (closed circles), C. retiniana (Wlsm.) (open circles), C. carnana carnana (B. & Bsk.) (open triangles), and C. carnana californica Powell (closed triangles). Half-closed circles in southern Oregon and northern California indicate localities with possible hybrid populations. (Data from Stehr (1967) and specimens examined.)

the basis of the record. If occidentalis and retiniana were sympatric in northern California, it would not be possible to morphologically differentiate them except by degree of integumental sclerotization in the larva and pupa. Probably the record for occidentalis in California refers to a population discussed here under C. carnana californica.

Over the broad range of occidentalis there is considerable interpopulational variation in ecological and geographical features (such as host preferences and phenology), as well as in phenotype of the adults, particularly in existence and frequencies of polymorphic phases. Thus, many populations could be described in which the adults differ from typical occidentalis of eastern Washington.

Choristoneura biennis Freeman.--The 2-year life cycle form replaces C. occidentalis in interior British Columbia and northward. Freeman (1967) and Stehr (1967) listed two Picea species and Abies lasiocarpa as host plants, not specifying which are used in various parts of the range--reported to include mountains of western Alberta and southwestern Yukon Territory.

Choristoneura orae Freeman.--Apparently, there have been no further data on the geographical range of this species or its relationship with occidentalis to the south and biennis in the interior of British Columbia at the same latitude.

Carnana Complex

Choristoneura carnana (Barnes and Busck).--The typical form of this species is known in the literature or from the type series and from one specimen collected at Mount Lowe in t San Gabriel Mountains (Powell 1964, p. 184). Recently it has been collected in the Mount Baldy area in associatio with Pseudotsuga macrocarpa. To the north, along the west slope of the Sierra Nevada, there are populations exhibiting a similar, monomorphic phenotype, but individuals have more e extensive, darker rust-orange forewin markings and darker hindwings. Sever collections of the latter have been made since my summary of the distribution (Powell 1964: map 9), an its occurrence appears to be restrict to elevations below 1 700 m (5,500 feet), corresponding to the range of Pseudotsuga menziesii. Larvae were collected and reared from that host i El Dorado County in 1979.

Choristoneura carnana californica Powell.--The Coast Range populations northern California were considered along with carnana to be probable pine-feeders because of their allopatric displacement of C. lambertiana and subretiniana (Powell 1964). Subsequently, however, C. carnana californica has been reared from

Pseudotsuga menziesii in Napa and Lake Counties, near the type locality. Larvae of these and the El Dorado County populations are heavily marked, brick red, similar to certain forms described for C. occidentalis (Harvey and Stehr 1967), contrasting markedly with the green Abies-feeding larvae of retiniana. The Choristoneura recorded as californica from lower elevations around Mount Shasta (Powell 1964, p. 181) has been reared from Pseudotsuga in the Salmon River area of the Siskiyou Mountains by Carolin, Volney, and Waters.

These records, together with the Pseudotsuga-associated distribution of the Sierran west slope populations and carnana carnana, indicate this complex is primarily associated with Abietoideae, not Pinoideae as was previously supposed. This is the first known instance of two sympatric species using Abietoideae. C. carnana (in the broad sense) occurs within a few kilometers of Abies-feeding retiniana at Mount Shasta City (about 600 m--2,000 feet--lower in elevation), and the two species fly together at the same sites in mixed Pseudotsuga-Abies forests on the west slope of the Sierra Nevada (e.g., El Dorado County at 1 300 m--4,250 feet) and in the San Gabriel Mountains (fig. 1).

Western Components of the Lambertiana Complex

Choristoneura lambertiana lambertiana (Busck).--Other than the original series, reared from sugar pine in the vicinity of Ashland, Oregon, the typical race of this species is known only from one collection, from Pinus lambertiana in adjacent Siskiyou County, California. Freeman (1958, p. 36) listed lambertiana from California and New Mexico and cited Juniperus (Cupressaceae) as a food plant, without specific data--the last probably based on misidentified specimens of Cudonigera houstonana. Stehr (1967, p. 461) mentioned a form with pale, washed out forewings within populations of this species (e.g., Obraztsov 1962: figs. 7 and 8) but equated this pale form with ponderosana, populations of which consist entirely of a more extreme washed out phenotype (Obraztsov 1962: figs. 30-31).

Northern Rocky Mountain moths are somewhat intermediate, exhibiting a mixture of color pattern features of typical lambertiana, subretiniana of eastern Oregon, and ponderosana in Colorado. The concept of lambertiana was expanded to include these populations in Idaho, Montana, and Wyoming by Obraztsov (1962) and Stehr (1967), and some Montana and Wyoming populations were included in C. l. ponderosana by Stevens et al. (1977). There appears to be clinal change in phenotype in a broad arc through the northern Rocky Mountain States (fig. 2).

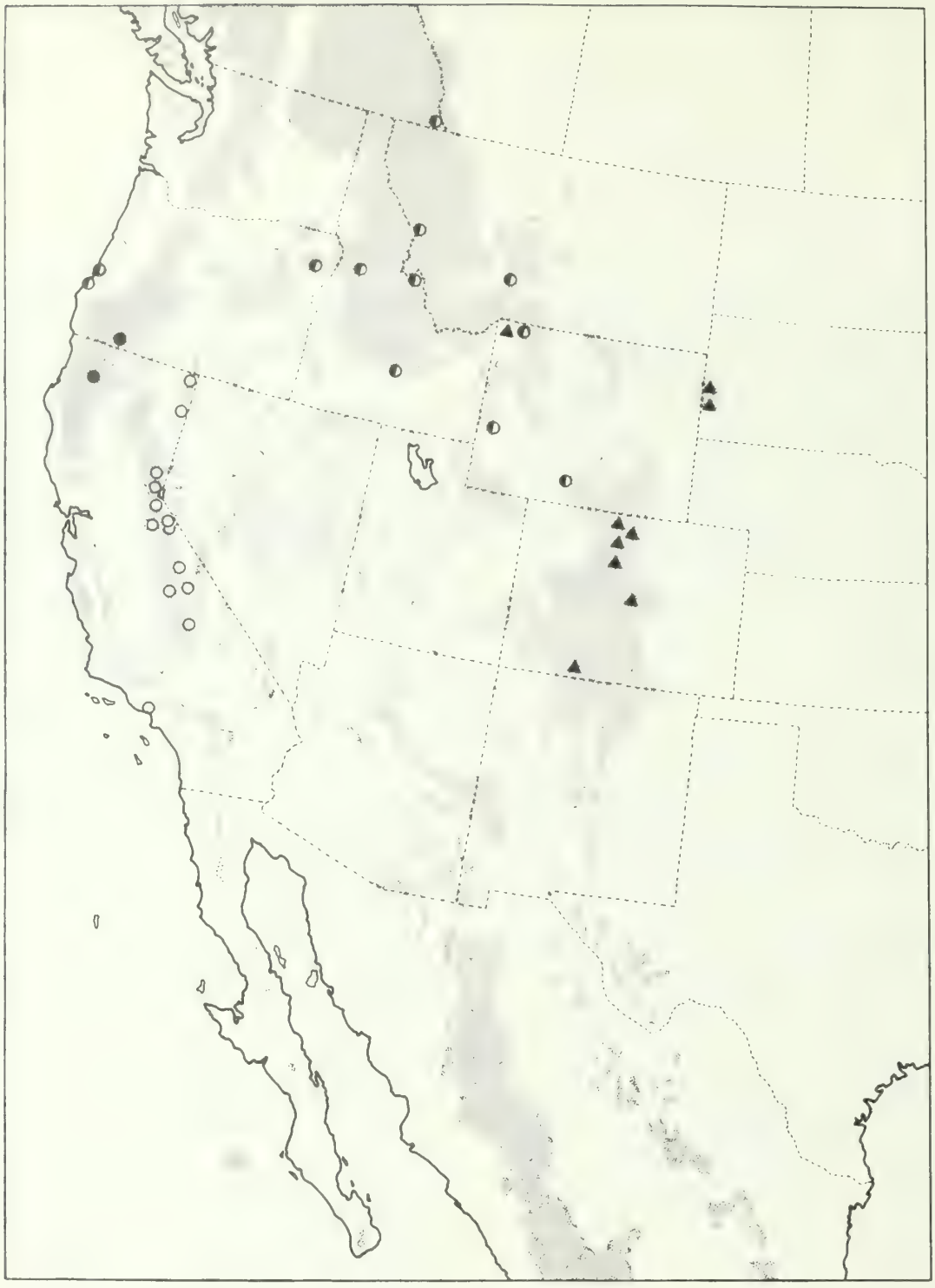


Figure 2.--Distribution of western Nearctic members of the Pinoideae-feeding Lambertiana complex: Choristoneura lambertiana lambertiana (Bsk.) (closed circles), C. lambertiana subretiniana Obr. (open circles), C. lambertiana ponderosana Obr. (triangles). Half-closed circles indicate populations referred to lambertiana s.str. by Obraztsov (1962) or Stehr (1967) and/or represented by more recent material of uncertain relationships. (Additional data are from Stevens et al. (1977) and specimens examined.)

Shaded areas on figures 1 and 2 depict major topographic features; areas above 5,000 feet (1 530 m) are shaded for all but the central coastal area of California (2,000 ft--600 m) and Great Basin region (7,000 ft--2 150 m), matching fairly well the distribution of coniferous woodland.

Choristoneura lambertiana subretiniana Obraztsov.--This race occurs in eastern Sierra Nevada lodgepole pine forests from Tulare County north to Plumas County, in the Warner Mountains, and, in a slightly different phenotype, in Harney County of eastern Oregon (fig. 2). It has been reared from lodgepole pine in Nevada County (Stark and Borden 1965) and Warner Mountains (Powell 1964, p. 183; Pierce and Hall 1974). Northward from the California border, the phenotype loses the gray color, especially on the forewing interstices between the rust-red banding, and begins to resemble the form prevalent in Idaho and Montana. Harvey and Stehr (1967), who followed Obraztsov in treating subretiniana as a species, cited six larval collections, including three from pine (Pinus contorta, P. jeffreyi, and P. washoensis) and one from Abies concolor, apparently all from the area of Lake Tahoe.

Choristoneura lambertiana ponderosana Obraztsov.--This distinctive race, in which the forewings have no rust or reddish markings, has been recorded at numerous sites along the eastern flank of the Rocky Mountains in Colorado, in extreme southern Colorado near Durango, as well as in Montana, South Dakota, and Wyoming (Stevens et al. 1977). Pinus ponderosa is the host in each recorded instance except in Montana, where Pinus flexilis is used in the same area from which Stehr (1967: fig. 1) assigned populations to lambertiana s.str. (fig. 2).

Uncertain Status

Choristoneura spaldingiana Obraztsov.--This form is too poorly known to associate with any of the above defined complexes. Described from Provo, Utah, at the western edge of the Wasatch Range, data are too sketchy to indicate a probable host. A typical phenotype of C. occidentalis occurs at higher elevations in the Wasatch Range, but no population of the Lambertiana complex is recorded there. Adults which are phenotypically similar to spaldingiana have been collected in the Schell Creek Range of eastern Nevada. The moths were taken in a pure stand of Abies concolor, which suggests the possiblity that the name spaldingiana represents a pallid form of the Fumiferana complex in the foothills or dry ranges of the Great Basin.

CONCLUSIONS

It is important to understand that names applied to both Abietoideae- and Pinoideae-feeding Choristoneura, particularly in western North America, are little more than signs posted at irregular intervals on mosaics of differing populations. Any attempt to define species as reproductively isolated entities of comparable rank or genetic integrity on the basis of present knowledge will be artificial. Adults vary phenotypically between populations in average size, color, extent and kind of wing markings; larvae and pupae vary in intensity of integumental color; populations differ in whether or not genetic polymorphism is expressed and, if so, in the proportions of the polymorph phases. Physiological and behavioral traits also vary in response to ecological and geographical factors, so that host preferences, seasonal timing of stages, cold-hardiness, and other features differ from place to place independently of the phenotype.

Entomologists should realize that there is every reason to expect that a given population of either the Fumiferana complex or Lambertiana complex will differ in some respects from typical populations representing available species names. For example, many populations assigned to C. occidentalis, especially those of the far north, Great Basin ranges, and southern Rocky Mountains, vary phenotypically to a degree comparable with that to which named "species" differ from typical occidentalis and from one another. Thus, nomenclatural recognition could have been given to many additional populations had there been physiological and genetic studies or were there a need for communication about them. Taxonomists should agree that application of any further names to this complex at our present state of knowledge would be absurd.

ITERATURE CITED

arnes, W., and A. Busck.
1920. Notes and new species. Contributions Nat. Hist. Lepid. N.A. 4(3):209-278.

arlington, E. P.
1947. Notes on certain types of Lepidoptera described by Brackenridge Clemens. Trans. Am. Entomol. Soc. 73(2):85-104.

yre, F. H. (Chairman), W. A. Dayton, . DenUyl, and others.
1967. Forest cover types of North America (exclusive of Mexico). Report of the Committee on Forest Types. 67 p. Soc. Am. For., Washington, D.C.

ernald, C. H.
1881. Oviposition in the Tortricidae. Am. Nat. 15(1):63-66.

erré, Y. de.
1952. Les formes de jeunesse des-Abiétacées, Ontogénie-Phylogénie. In Études Dendrologiques. 1. Les Gymnospermes-généralités, vol.3(1). Traveaux Lab. For., Toulouse. 284 p.

reeman, T. N.
1947. A new generic assignment for Archips fumiferana (Clemens), the spruce budworm. Can. Entomol. 79(1):21.

reeman, T. N.
1958. The Archipinae of North America (Lepidoptera: Tortricidae). Can. Entomol. 90 (suppl. 7), 87 p.

reeman, T. N.
1967. On coniferophagous species of Choristoneura (Lepidoptera: Tortricidae) in North America. I. Some new forms of Choristoneura allied to C. fumiferana. Can. Entomol. 99(5):449-455.

Grote, A. R.
1881. "North American Tortricidae", by Lord Walsingham, London, 1879. Papilio 1(1):8-9.

Harvey, G. T.
1967. On coniferophagous species of Choristoneura (Lepidoptera: Tortricidae) in North America. V. Second diapause as a species character. Can. Entomol. 99(5):486-503.

Harvey, G. T., and G. W. Stehr.
1967. On coniferophagous species of Choristoneura (Lepidoptera: Tortricidae) in North America. III. Some characters of immature forms helpful in the identification of species. Can. Entomol. 99(5): 464-481.

Heinrichs, E. A., and H. E. Thompson.
1968. The biology of Choristoneura houstonana (Lepidoptera: Tortricidae), a pest of Juniperus species. Can. Entomol. 100(7): 750-763.

Hodges, R. W., D. R. Davis, W. D. Duckworth, and others.
[In press.] Checklist of Lepidoptera of America north of Mexico (Microlepidoptera Families). E. W. Classey Ltd. and Wedge Entomol. Found., London.

Miller, W. E.
1973. Clemens types of Olethreutinae (Lepidoptera, Tortricidae). Trans. Am. Entomol. Soc. 99(3):205-234.

Obraztsov, N. S.
1962. New species and subspecies of North American Archipini, with notes on other species (Lepidoptera, Tortricidae). Am. Mus. Novit. 2101:1-26.

Pierce, J. R., and R. C. Hall.
1974. A biological evaluation of sugar pine tortrix on the Modoc National Forest in 1974. 10 p. USDA For. Serv., San Francisco.

Powell, J. A.
1964. Biological and taxonomic studies on tortricine moths, with reference to the species in California. Univ. Calif. Publ. Entomol. 32, 318 p.

Powell, J. A., and N. S. Obraztsov.
1977. Cudonigera: A new genus for moths formerly assigned to Choristoneura houstonana (Tortricidae). J. Lepid. Soc. 31(2):119-123.

Stark, R. W., and J. H. Borden.
1965. Life-history of Choristoneura lambertiana subretiniana Obraztsov (Lepidoptera: Tortricidae) attacking lodgepole pine. Can. Entomol. 97(7):684-690.

Stehr, G. W.
1964. The determination of sex and polymorphism in microevolution. Can. Entomol. 96(1-2):418-428.

Stehr, G. W.
1967. On coniferophagous species of Choristoneura (Lepidoptera: Tortricidae) in North America. II. Geographic distribution in accordance with forest regions. Can. Entomol. 99(5):456-463.

Stevens, R. E., T. K. Borg, and T. O. Thatcher.
1977. Notes on a pine-feeding budworm, Choristoneura lambertiana ponderosana (Lepidoptera: Tortricidae), in the Colorado Rockies. Can. Entomol. 109(9):1269-1274.

Sutherland, W. S., W. F. Barr, C. A. Barlow, and others.
1978. Common names of insects and related organisms. Entomol. Soc. Am. 132 p. rev. Spec. Publ. 78-1. College Park, Md.

Walsingham, Lord Thos. de Grey.
1879. North American Tortricidae. Illus. Lepid. Heterocera Br. Mus. 4, 84 p. Br. Mus., London.

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